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WINDING ALTERNATING - CURRENT MACHINES

A Book for Winders, Repairmen, and Designers of Electric Machines

BY

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D. VAN NOSTRAND COMPANY, INC.
TORONTO NEW YORK LONDON

NEW YORK
D. Van Nostrand Company, Inc., 250 Fourth Avenue, New York 3
TORONTO
D. Van Nostrand Company (Canada), Ltd., 228 Bloor Street, Toronto
LONDON
Macmillan & Company, Ltd., St. Martin's Street, London, W.C. 2

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Published simultaneously in Canada by
D. VAN NOSTRAND COMPANY (Canada), LTD.

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PRINTED IN THE UNITED STATES OF AMERICA

TO

MY CHILDREN

I dedicate my work

PREFACE

This book is written for the winder and repairman; it will be useful also to the design-engineer. It is the first comprehensive presentation of lap as well as wave windings. It contains new developments in integral-slot, fractional-slot balanced, and fractional-slot unbalanced lap and wave windings.

Each chapter gives first the "know how," in order to make it possible for the reader to find the answer easily to his particular winding problem. This is facilitated by detailed information on coil insulation and a series of tables which show, without winding diagrams, all possible series and parallel connections for all pole numbers between 2 and 30. The end of each chapter gives general rules for the layout of windings not listed in the tables. The "why" is explained in appendices at the end of the book, where the reader may find the proof for the methods used.

The integral-slot, balanced fractional-slot, and unbalanced fractional-slot lap windings are treated in separate chapters, since their layout is based upon entirely different methods. A detailed treatment of the balanced and unbalanced fractional-slot lap windings is given for the first time on the basis of newly developed methods.

The wave windings are treated in detail for the first time. Also these windings are divided into three parts: integral-slot and integral plus half-slot windings, balanced fractional-slot windings, and unbalanced fractional-slot windings. Newly developed layout methods show how to make a fractional-slot wave winding balanced in all cases in which the fractional-slot lap winding is balanced and how to lay out an unbalanced winding for minimum unbalance. In order to facilitate the winder's work, a great number of working diagrams are given for all three kinds of wave windings.

Material is also presented on multi-speed windings, single-phase windings, reconnecting windings for changed operating conditions, and methods for locating faults in windings.

Brooklyn, N.Y.,
October, 1950

Michael Liwschitz-Garik

ACKNOWLEDGMENTS

A book on windings requires a large number of drawings, tables, and photographs. To write such a book without the help of an engineering department of a company specialized in the field is a task almost impossible to accomplish. This help has been given to the author by Mr. J.W. Overstreet, President of National Electric Coil Company, and Mr. N.J. Greene, Manager of Engineering of the same Company, who placed their Engineering and Drafting Departments at the author's disposal. The author is much indebted to these gentlemen for making possible the publishing of this book, and also to Mr. R.C. Bergvall, Engineering Manager, Industrial Products, of the Westinghouse Electric Corporation, and to the General Electric Company for their valuable contributions.

Very valuable assistance has been given to the author by Mr. Celso Gentilini, Assistant Chief Engineer of the National Electric Coil Company, who not only thoroughly checked the manuscript, drawings, and tables, but also made many practical and helpful suggestions and calculated a large number of examples. Also most of the proofreading has been done by Mr. Gentilini. The author is much indebted to him for his devoted collaboration.

An acknowledgment of appreciation is further due to Mr. Mario Gigante, of the National Electric Coil Company, for calculating Figure 5-2 and for thorough proofreading; to Prof. S. Garik, Mr. C.G. Veinott, Section Manager, Westinghouse Electric Corporation, and Mr. D.E. Stafford, Chief Engineer of the National Electric Coil Company, for helpful suggestions; to Mr. A.R. Levada for his work on Tables 5-5 and 5-6, and finally to Dr. V. L. Garik, Prof. E. Wahlers, and Mr. H.J. Huttenlocher for their help in proofreading.

M.Liwschitz-Garik

CONTENTS

1. CLASSIFICATION OF A-C WINDINGS AND SOME FUNDAMENTAL CONCEPTIONS

Page

1-1 Coil Group, Coil, Turn, Conductor, and Strand . . . 1

1-2 One, 2- and 3-Phase Windings. 1

1-3 Cycle and Frequency 1

1-4 Number of Poles, Synchronous Speed. 1

1-5 Slots per Pole per Phase. 2

1-6 Pole-Phase Group. 3

1-7 Pole Pitch. 3

1-8 Coil Pitch - Full-pitch Winding - Fractional-pitch Winding 4

1-9 Phase Beginnings. 4

1-10 Classification of A-c Windings. 5

2. TYPES AND INSULATION OF POLYPHASE WINDINGS

A. Lap Windings

2-1 Types of Lap Windings 12

(a) Round-end Winding 12

(b) Flat-diamond Winding. 13

(c) Pulled or Spread-diamond Winding. 14

2-2 Throw Coils 15

2-3 Straight-up Wound Pulled Coils and Cross-over Pulled Coils. 17

2-4 Stranding of Rectangular Conductors in Spread Coils 19

2-5 Starting and Finishing Lead 21

Left-hand and Right-hand Coils. Arrangement of Leads 22

2-6 Insulation of Conductors, Slots, and End Windings . 24

Conductor Insulation. 25

Strand Insulation 25

Ground Insulation 25

Ground Insulation of Semi-closed Slots. 26

Ground Insulation of Open Slots 27

End-winding Insulation. 27

Finishing and Varnishing the Coils. 28

Lead Insulation 28

Page

Insulation of Stub Connections, Jumper, and Tie Rings 29
Mechanical Clearances 30

B. Wave Windings

2-7 Insulation of Slots and End Windings. 32
Ground and End-winding Insulation 33
Separation of Upper and Lower Layer 34
Clip Insulation 35
Support Insulation. 35
Mechanical Clearances 35
Wedges. 36
Banding of the End Windings 36

C. Squirrel-cage Windings

2-8 Different Kinds of Squirrel-cage Windings 37

3. INTEGRAL-SLOT LAP WINDINGS
(Lap Windings With Equal Coil Grouping)

A. Connection Diagrams and Connection Tables

3-1 Windings Treated in This Chapter. 51
3-2 Presentation, Numbering, and Designation of Pole-phase Groups. 51
3-3 Connection Diagrams and Connection Tables and How to Use Them 52

B. Two-phase Windings

3-4 Layout of 2-phase Windings. 56
3-5 Short and Long Jumpers. 58
3-6 Location of the Beginnings of the Phases. 60
3-7 Checking of a 2-phase Winding 60
3-8 Dual-voltage Connections. 61

C. Three-phase Windings

3-9 Layout of 3-phase Windings. 62
3-10 Short and Long Jumpers. 65
3-11 Location of the Beginnings of the Phases. 66

Page
3-12 Checking a 3-phase Winding. 66
3-13 Star (Wye "Y") and Delta (△) Connection. 69
3-14 Dual-voltage Connections. 69
3-15 Magnetic Unbalance and Equalizer Connections. . . . 70

4. BALANCED FRACTIONAL-SLOT LAP WINDINGS
(Balanced Lap Windings with Unequal Coil Grouping)

4-1 Average Number of Slots per Pole per Phase. 207
4-2 Connection Diagrams and Coil Grouping 207
4-3 Coil Grouping Tables and How to Use Them. 208
4-4 Number of Larger and Smaller Pole-phase Groups; Number of Equal Winding Parts 211
4-5 General Rules 212
4-6 Conditions of Balance 212
4-7 Number of Parallel Circuits 213
4-8 Layout of a Balanced 2-phase Winding. 214
4-9 Beginnings of Phases in 2-phase Windings. 216
4-10 Layout of a Balanced 3-phase Winding. 217
4-11 Beginnings of Phases in 3-phase Windings. 218
4-12 Simplification in the Layout of Balanced 2-phase and 3-phase Windings. 219

5. UNBALANCED FRACTIONAL-SLOT LAP WINDINGS
(Unbalanced Lap Windings with Unequal Coil Grouping)

5-1 Two Kinds of Unbalanced Fractional-slot Lap Windings 232
5-2 Coil Grouping Tables and How to Use Them. 233
(a) The Number of Slots and the Denominator of the Fraction Are Both Divisible by the Number of Phases. 233
(b) The Number of Slots Is Not Divisible by the Number of Phases. 235
5-3 Connection Diagrams and Phase Beginnings. 237
5-4 Layout of an Unbalanced Fractional-slot Lap Winding When the Number of Slots Is Divisible by the Number of Phases 238
5-5 Layout of an Unbalanced Fractional-slot Lap Winding When the Number of Slots is Not Divisible by the Number of Phases. 241
5-6 Simplification of the Coil Grouping Tables of the Unbalanced Fractional-slot Lap Windings 247

Page
5-7 Permissible Degree of Unbalance 248

6. INTEGRAL-SLOT AND (INTEGRAL + 1/2)-SLOT 3-PHASE WAVE WINDINGS

6-1 General Features of the Wave Winding. Back Pitch, Front Pitch, Winding Pitch, Reversing Jumper. . . . 264
6-2 Different Ways of Starting and Winding the 3 Phases. Retrogressive and Progressive Windings, Short-pitch and Long-pitch Coils. 266
    A. Windings with spp = integer
        (a) Retrogressive (SP) connection 266
        (b) Progressive-retrogressive (LP-SP)connection 270
        (c) Progressive (LP) connection 272
        (d) Retrogressive (SP) connection using right-hand coils. 272
    B. Windings with spp = (integer + 1/2)
        (a) Retrogressive (SP) connection 274
        (b) Progressive-retrogressive (LP-SP)connection 275
6-3 Connection Tables, Conductor Distribution Tables, Working Diagrams, and How to Use Them 277
6-4 General Rules for Laying Out Conductor-distribution Tables and Connection Tables. 291
6-5 General Rules for Laying Out a Working Diagram. . . 297
6-6 Wave Windings with More than 2 Conductors Per Slot. 301
6-7 Series Star and Series Delta Connection of Phases . 306
6-8 Two Parallel Star and 2 Parallel Delta Connections. 306
6-9 Integral-slot Windings with More than 2 Parallel Circuits. 307
6-10 (Integral + 1/2)-slot Windings with 2 and More than 2 Parallel Circuits 317

7. BALANCED FRACTIONAL-SLOT WAVE WINDINGS

7-1 Features of the Windings Treated in This Chapter. . 396
7-2 Connection Tables and How to Use Them 397
7-3 Working Diagrams. 398
7-4 Winding Pitch, Back Pitch, and Front Pitch. Number of Repeatable Parts. General Rules 401
7-5 Maximum Possible Number of Parallel Circuits. . . . 405

Page
7-6 Polarities of the Starts and Ends of the Winding Parts 406
7-7 Beginnings of Phases. 407
7-8 Number of Connectors Required for Series Connection of All Parts of the Phase 407
7-9 Layout of a Winding with a = ± 1. 408
7-10 Layout of a Winding with a = ± 2, and N = Even Number 415
7-11 Layout of a Winding for a = ± 2, and N = Odd Number 425
7-12 Layout of a Winding with a Larger than 2. 430
7-13 Layout for 2 or More Parallel Paths 433

8. UNBALANCED FRACTIONAL-SLOT WAVE WINDINGS

8-1 Features of the Windings Treated in This Chapter. . 502
8-2 Connection Tables and How to Use Them 502
8-3 Working Diagrams. 505
8-4 Winding Pitch, Back Pitch, and Front Pitch. General Rules 506
8-5 Layout of a Winding with a Number of Slots Divisible by 3 and the Denominator of spp = 3 508
8-6 Layout of a Winding with a Number of Slots Divisible by 3 and the Denominator of spp = 6 512
8-7 Layout of a Winding with a Number of Slots Divisible by 3 and the Denominator of spp = 9 517
8-8 Layout of a Winding with a Number of Slots Not Divisible by 3. 525
8-9 Magnitude of Unbalance. 529

9. TWO AND MORE SPEED POLYPHASE WINDINGS

9-1 Two Speeds with the Ratio 2 to 1. 565
9-2 Two Speeds with a Ratio Different from 2 to 1 . . . 567
9-3 Three Speeds, 2 of Which Have the Ratio 2 to 1. . . 570
9-4 Four Speeds with 2 Pairs Having the Ratio 2 to 1. . 570

10. RECONNECTING AN OLD POLYPHASE WINDING FOR NEW CONDITIONS AND REWINDING AN OLD CORE

10-1 Relation Between Voltage, Flux, Number of Turns, and Frequency 589

Page

10-2 Reconnecting for Another Voltage. 590

10-3 Reconnecting for Another Frequency. 594

(a) The Speed Changes in Proportion to the Frequency 594

(b) The Speed Remains the Same at Both Frequencies. 597

10-4 Effective Number of Turns. Distribution Factor and Pitch Factor. 597

10-5 Reconnecting for Another Speed. 598

10-6 Reconnecting for Another Number of Phases 602

10-7 Determination of the Horsepower from Given Dimensions of a Motor. 606

10-8 Rewinding an Old Core 606

11. SINGLE-PHASE WINDINGS AND DIAGRAMS

11-1 Various Types of Single-phase Motors. 609

1. Split-phase motor 609
2. Resistance-start, split-phase motor 609
3. Reactor-start, split-phase motor. 610
4. Capacitor-start motor 610
5. Permanent-split capacitor motor 610
6. Two-value capacitor motor 610
7. Repulsion motor 610
8. Repulsion-start induction motor 610
9. Repulsion-induction motor 610
10. Universal motor 610
11. Shaded-pole motor 611
12. Split-phase reluctance motor. 611
13. Capacitor-type reluctance motor 611
14. Capacitor-type hysteresis motor 611
15. Shaded pole hysteresis motor. 611

11-2 Stator Windings 612

(a) Hand Windings. 613

(b) Mould Windings 614

(c) Skein Windings 615

11-3 Insulation of the Wire and the Slots of Stator. . . 622

11-4 Different Types of Stator Diagrams. 624

(a) The Distribution Chart 624

(b) Common Connection Diagrams 626

Page
(c) Wiring Diagram and Line-connection Diagram. . . 632
11-5 Dual-voltage Motors 634
11-6 Two-speed Motors. 637
(a) Two-speed motors with 2 winding sets 637
(b) Two-speed motors with tapped windings. 639
11-7 Repulsion-type Motors 642
11-8 Pre-determining the Direction of Rotation and reversing of Split-phase Type Motors. 644
11-9 Reconnecting or Rewinding a Split-phase Motor for a Different Voltage at the Same Performance 645
11-10 Reconnecting or Rewinding a Capacitor-start Motor for a Different Voltage at the Same Performance . . 646
11-11 Reconnecting or Rewinding a Permanent-split and a 2-value Capacitor Motor for a Different Voltage at the Same Performance. 647
11-12 Rewinding for a Different Breakdown Torque at the Same Voltage. 648
11-13 Rewinding for a Different Frequency 649
11-14 Changing a Split-phase Motor to a Capacitor-start Motor 649
11-15 Changing a Capacitor-start Motor to a Split-phase Motor 649
11-16 Changing a 2-value Capacitor Motor with Transformer Unit to a Capacitor-start Motor 650

12. ELECTRICAL FAULTS IN A-C WINDINGS

12-1 Grounds 658
12-2 Short Circuits. 659
12-3 Wrong Connections 661
12-4 Connection for Wrong Voltage. 663
12-5 Connection for Wrong Number of Poles. 664
12-6 Open Circuits 664

APPENDIX 1

Balanced Fractional-slot Lap Windings Laid Out With Respect to the Main Wave

A1-1 Number of Repeatable Groups and Parallel Paths. . . 670
A1-2 The Slot Star 670

Page

A1-3 The Layout of a Balanced Fractional-slot Lap Winding 675

A1-4 Beginnings of Phases 681

A1-5 Conditions for Balance 682

APPENDIX 2

Balanced Fractional-Slot Lap Windings Laid Out With Respect to Harmonics (Windings with Cyclic Coil Shift and Doubly Chorded Windings)

A2-1 Cyclic Shift of Coils from One Phase to the Other Within the Same Repeatable Group 683

A2-2 Shifting of Repeatable Winding Parts with Respect to Each Other (Second Chording) 688

APPENDIX 3

Balanced Fractional-slot Wave Windings With Single and Double Chording

A3-1 The D-series and the y-series 691

A3-2 The Winding Pitch 691

A3-3 Layout of a Singly Chorded, Balanced, Fractional-slot Wave Winding 692

A3-4 Doubly Chorded, Balanced, Fractional-slot Wave Windings 696

APPENDIX 4

Unbalanced, Fractional-slot Lap and Wave Windings

A4-1 Unbalanced, Fractional-slot Lap Windings with $\frac{S}{m} =$ Integer and $\frac{d}{m} =$ Integer 701

A4-2 Unbalanced, Fractional-slot Lap Windings with $\frac{S}{m} \neq$ Integer 704

A4-3 Comparison Between the Balanced and Unbalanced Lap Windings 706

A4-4 Unbalanced, Fractional-slot Wave Windings with $\frac{S}{m} =$ Integer and $\frac{d}{m} =$ Integer 707

A4-5 Unbalanced, Fractional-slot Wave Windings with $\frac{S}{m} \neq$ Integer 709

A4-6 Determination of the Magnitude of Unbalance 711

Page

(a) $\frac{S}{m}$ = an integer. 711

(b) $\frac{S}{m} \neq$ an integer. 714

(c) Simple method for checking the errors in the angles. 716

APPENDIX 5

Distribution and Pitch Factors of Integral and Fractional-slot Windings

A5-1 Integral-slot Windings 719

(a) Three-phase 60° phase belt (6-zone) stator windings. Distribution Factors 719

(b) Three-phase 60° phase belt (6-zone) rotor windings. 721

(c) Three-phase 120° phase belt (3-zone) stator windings. Distribution Factors 721

(d) Two-phase stator windings. Distribution Factors 723

(e) Single-phase windings 723

A5-2 Balanced, Fractional-slot Windings Laid Out For Maximum Distribution Factor of the Synchronous (Main) Wave 724

(a) Three-phase (6-zone) stator windings. 724

(b) Three-phase (6-zone) rotor windings 726

(c) Two-phase stator windings 726

LIST OF SYMBOLS. 747

BIBLIOGRAPHY 750

INDEX OF DIAGRAMS. 752

INDEX OF TABLES. 759

GENERAL INDEX. 762

CHAPTER 1

CLASSIFICATION OF A-C WINDINGS AND SOME FUNDAMENTAL CONCEPTIONS

The windings considered in this book are those which carry alternating current, are embedded in slots, and are not connected to a commutator.

1-1. Coil Group, Coil, Turn, Conductor, and Strand. Each winding consists of a number of coils arranged in coil groups, and each coil group may have one or more single coils. A coil consists of one or more turns connected in series and each turn consists of two conductors connected in series by end connections. A conductor may be made up of one strand or 2 or more parallel strands.

1-2. One, 2- and 3-Phase Windings. The a-c windings are single-phase, 2-phase, or 3-phase, corresponding to the number of phases of the lines to which they are connected. In 2- and 3-phase windings, the slots per pole are divided into 2 or 3 parts, one part for each phase. The number of slots per pole is determined by the total number of slots and the number of poles. The latter is determined by the number of cycles and the speed.

1-3. Cycle and Frequency. A period is the time necessary for an alternating electromotive force or current to change from one positive maximum to the next following positive maximum. During this time, the alternating electromotive force or current goes through a complete cycle, i.e., it accepts all possible positive as well as negative values. Power lines in the United States carry currents of either 60 or 25 cycles per second. In Europe, the lines usually carry currents of 50 cycles per second. The number of cycles per second is called frequency.

1-4. Number of Poles, Synchronous Speed. The number of poles is determined by the following rule:

$$\text{No. of poles} = \frac{120 \times \text{Frequency}}{\text{Speed (in rpm)}} \qquad (1\text{-}1)$$

Fig. 1-1 shows a 4-pole rotor of a synchronous machine with salient poles. In induction motors and synchronous machines with cylindrical rotors (turbo-generators), the poles are not

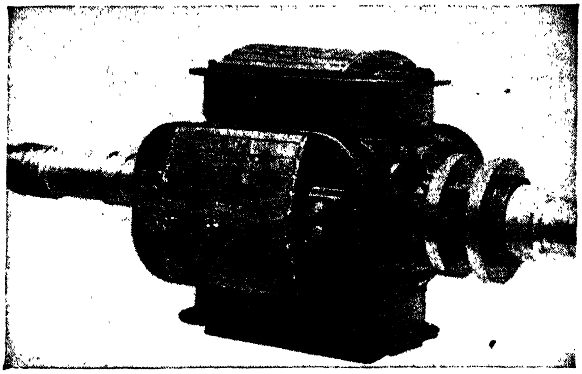


Fig. 1-1. Complete rotor of a 4-pole synchronous machine with salient poles

obvious mechanically, but, magnetically, they are as pronounced as in the salient pole machines. Two adjacent poles always have different polarities.

It follows from Eq. 1-1 that:

$$\text{Speed (in rpm)} = \frac{120 \times \text{Frequency}}{\text{No. of poles}} \qquad (1\text{-}2)$$

Cons/Engl

The speed obtained from this equation is called synchronous speed. A synchronous generator or motor runs with exact synchronous speed. The actual speed of the rotor of an induction motor is somewhat below the synchronous speed.

The corresponding values of synchronous speed and number of poles for frequencies of 60, 50, and 25 cycles are given in Table 1-1, shown on Page 3.

1-5. Slots Per Pole Per Phase. As already mentioned, the number of slots per pole for 2-phase or 3-phase windings is divided into 2 or 3 parts, respectively. The number of slots per pole per phase is, therefore, equal to the number of slots per pole divided by the number of phases or to the total number of slots divided by the number of poles and by the number of phases. The number of slots per pole per phase is an important quantity in the layout of a-c windings. The symbol spp will be used for this quantity. Thus,

$$\text{spp} = \frac{\text{Total No. of slots}}{\text{No. of poles} \times \text{No. of phases}} \qquad (1\text{-}3)$$

TABLE 1-1. SYNCHRONOUS RPM FOR DIFFERENT NUMBERS OF POLES AND DIFFERENT FREQUENCIES

No. of Poles	Frequency in Cycles		
	25	50	60
	Synchronous Rpm		
2	1500	3000	3600
4	750	1500	1800
6	500	1000	1200
8	375	750	900
10	300	600	720
12	250	500	600
14	214	428	514
16	187	375	450
18	167	333	400
20	150	300	360
22	136	273	327
24	125	250	300
26	115	231	277
28	107	214	257
30	100	200	240
32	94	187	225

1-6. Pole-phase Group. The coils lying in slots which belong to one phase and which are under one pole, i.e., the coils lying in spp slots make a coil group which is called a pole-phase group. The total number of pole-phase groups of 2-layer windings (see Fig. 1-4) is determined by the number of poles and the number of phases, i.e.,

No. of pole-phase groups = No. of poles x No. of phases (1-4)

and the number of single coils per pole-phase group is equal to the spp.

1-7. Pole Pitch. The pole pitch is the distance between the middle of 2 poles (see Fig. 1-1). It is equal to the circumference of the armature divided by the number of poles, i.e.,

$$\text{pole-pitch} = \frac{3.14 \times \text{Diameter of the armature}}{\text{No. of poles}} \qquad (1\text{-}5)$$

In 2-phase windings, the spp is equal to the number of slots lying in 1/2 or approximately in 1/2 of a pole pitch and, therefore, a pole-phase group covers 1/2 or approximately 1/2 of a pole pitch. In 3-phase windings, the spp is equal to the number of slots lying in 1/3 or approximately 1/3 of a pole pitch, and, therefore, a pole-phase group covers 1/3 or approximately 1/3 of a pole pitch. The 3-phase windings which are an exception to this rule are treated in Chapter 9.

1-8. Coil Pitch - Full-pitch Winding - Fractional-pitch Winding. The coil pitch is the distance between the 2 sides of a coil measured in pole pitches on the periphery of the armature. Fig. 1-2 illustrates this for a 4-pole machine. When the coil pitch is equal to a pole pitch, the winding is called a full-pitch winding. When the coil pitch is smaller or larger than the pole pitch, the winding is called a fractional-pitch or a chorded winding. The coil pitch is usually smaller than the pole pitch.

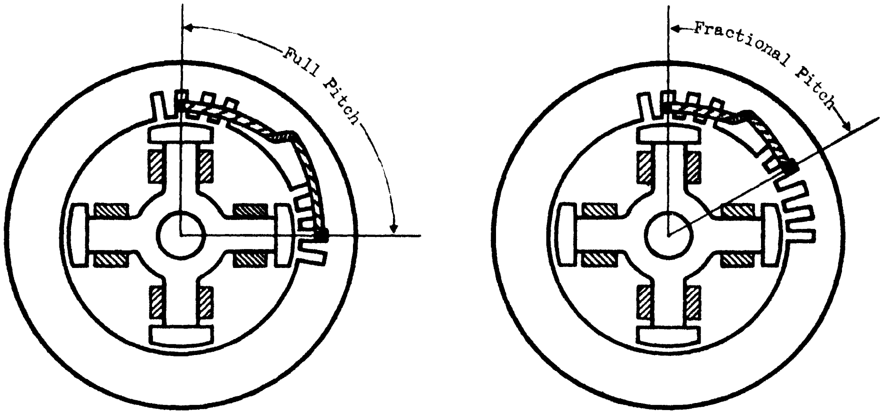


Fig. 1-2. Illustration of a full-pitch and a fractional-pitch winding

1-9. Phase Beginnings. The phase beginnings of the coil groups are the ends connected to the lines (or to slip rings in wound rotor induction motors). In 2-phase windings, the beginnings of the phases must lie 1/2 a pole pitch or approximately 1/2 a pole pitch apart. In 3-phase windings, the beginnings of the phases must lie 2/3 of a pole pitch or approximately 2/3 of a pole pitch apart. However, any even number of pole pitches can be added to these distances. For example, in a 2-phase winding, the 2 beginnings can be (1/2 + 2) = 2 1/2 pole pitches apart and, in a 3-phase winding, the second phase can start in a slot which is (2/3 + 2) = 2 2/3 pole pitches distant from the start of the first phase;and the third phase can start in a slot which is 2/3 + 2/3 + 2 = 3 1/3 pole pitches distant from the start of the first phase. The phase beginnings cannot be chosen arbitrarily. Rules for their choice are given in the following chapters.

1-10. Classification of A-c Windings. The a-c windings can be classified from several points of view. The following considerations are of importance:

1. Single-phase or polyphase.
2. Single-layer or 2-layer (Figs. 1-3 and 1-4).
3. Semi-closed slot or open slot (Figs. 1-5, 2-19, 2-22, 2-27).
4. Chain or distributed (Figs. 1-6 and 1-7).

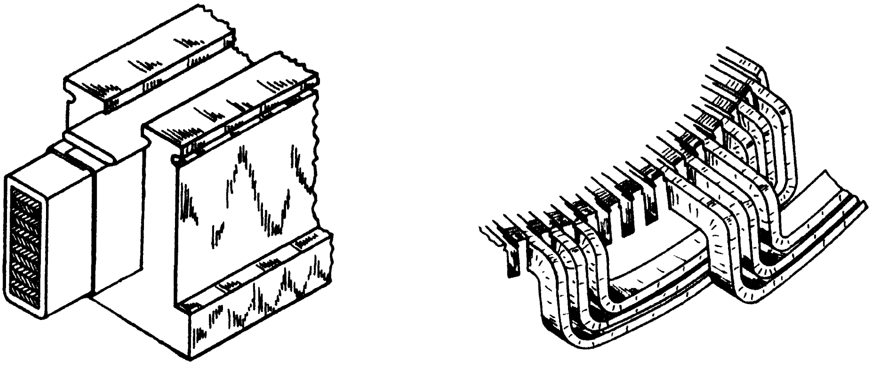


Fig. 1-3. Single-layer winding

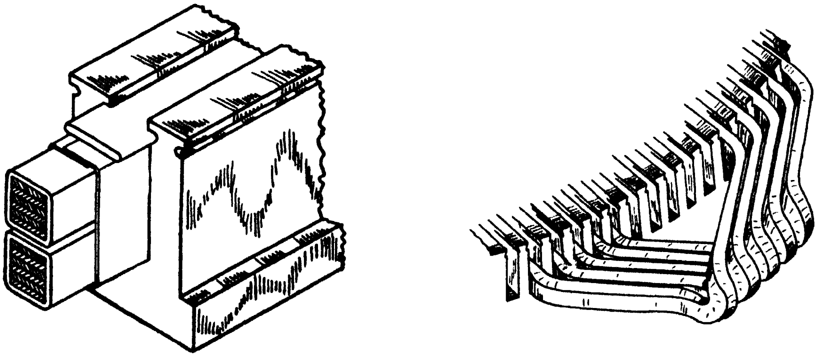


Fig. 1-4. Two-layer winding

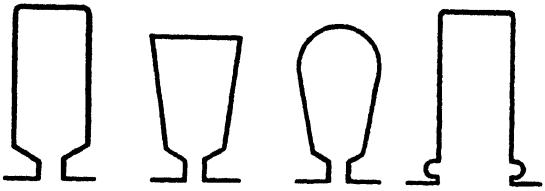


Fig. 1-5. Semi-closed and open stator and rotor slots

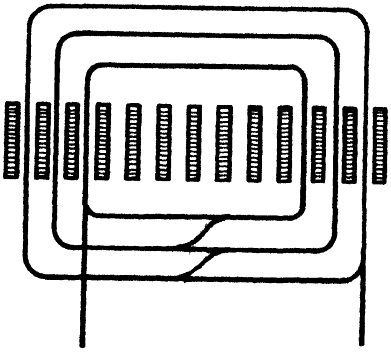


Fig. 1-6. Chain winding

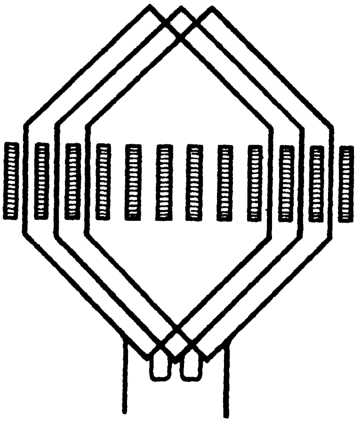


Fig. 1-7. Distributed winding

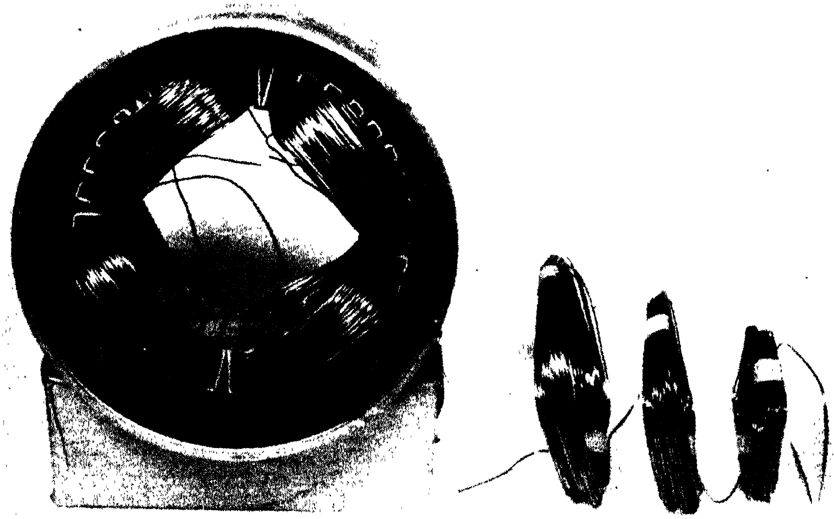


Fig. 1-8. Mould winding

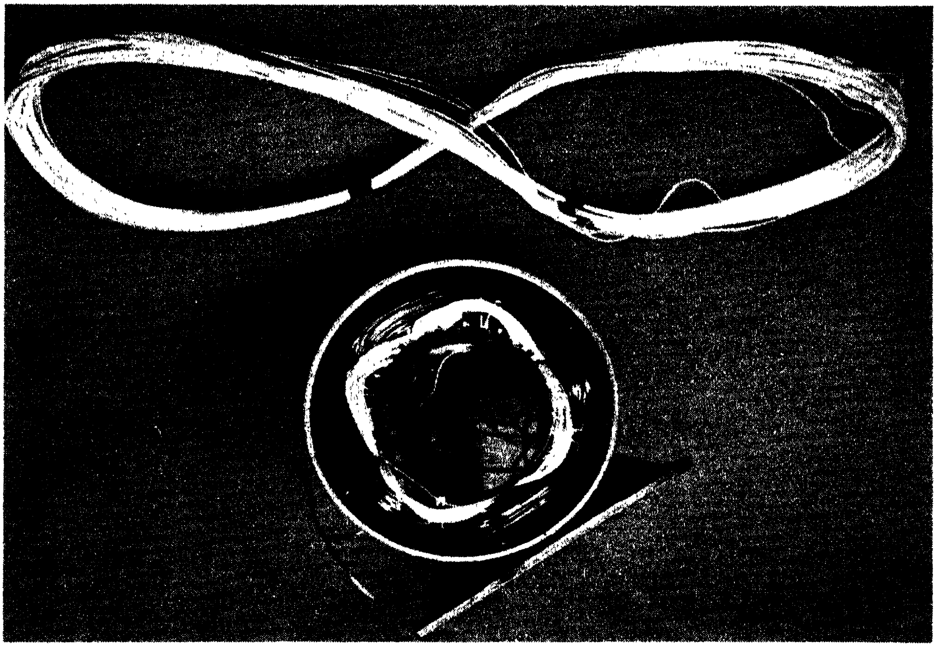


Fig. 1-9. Skein Winding

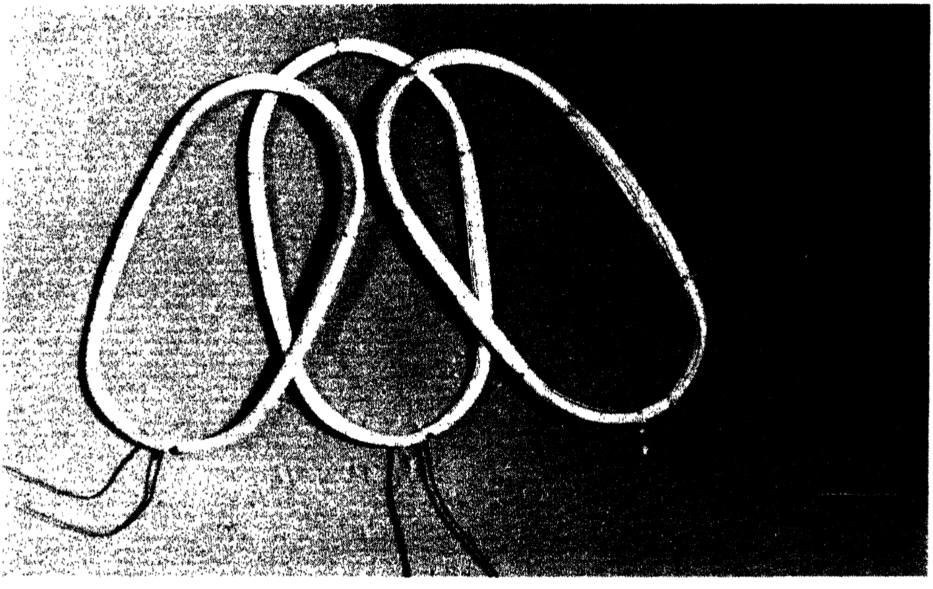


Fig. 1-10. Round-end winding

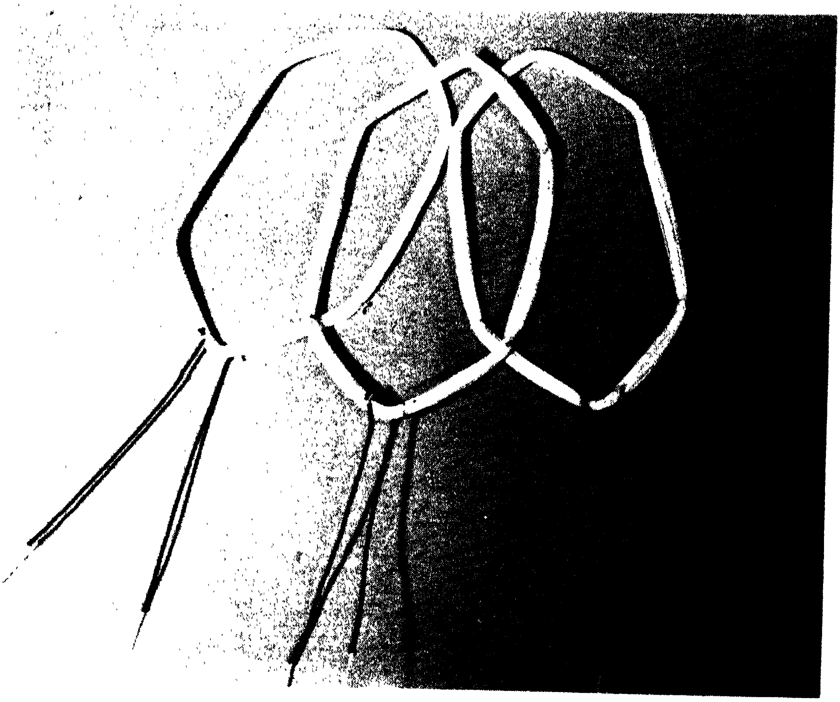


Fig. 1-11. Flat-diamond winding

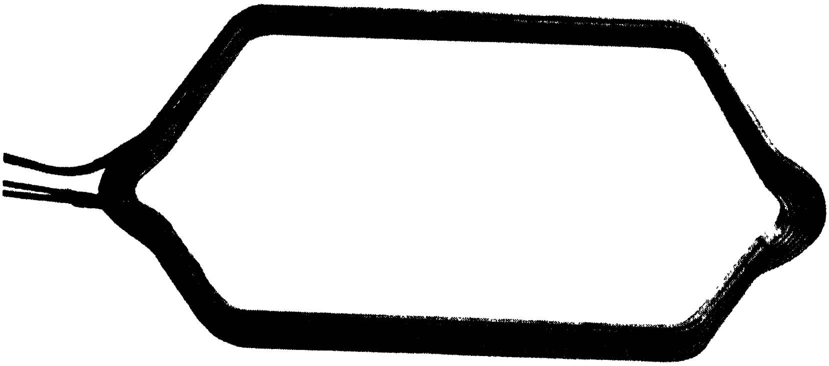


Fig. 1-12. Spread-diamond winding

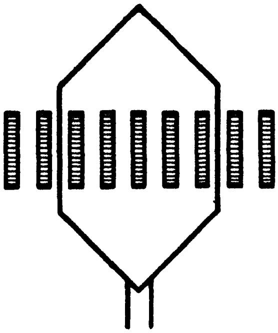


Fig. 1-13. Lap winding

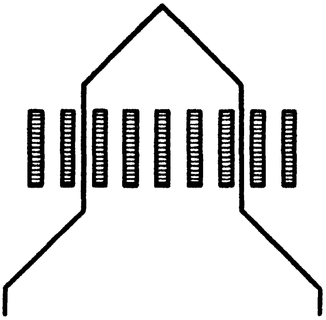


Fig. 1-14. Wave winding

5. Method of manufacture.
   (a) Single-phase - hand, mould, or skein winding (Figs. 1-8 and 1-9)
   (b) Polyphase - round-end, flat-diamond, or spread-diamond winding (Figs. 1-10, 1-11, and 1-12).
6. Round or rectangular wire section.
7. Lap or wave (Figs. 1-13 and 1-14).
8. Star or delta.
9. Full-pitch or fractional-pitch (Fig. 1-2).
10. Integral-slot or fractional-slot.

Single-phase motors are generally of small output (usually of fractional horsepower),and the stators are usually wound with chain windings placed in semi-closed slots. The coil sides of each coil lie in the same plane,i.e., both coil sides lie either at the bottom or at the top of the slot. The coils may be wound of round wire on moulds or in skeins and later installed in the core slots, as shown in Fig. 11-2 or the coils may be wound directly into the core by hand or by semi-automatic machine. The rotor of a single-phase motor has usually a squirrel-cage winding.

Polyphase motors usually have 2-layer windings. The 2 coil sides of each coil lie in different planes, i.e., one coil side lies at the bottom of the slot,the other at the top of the slot. The smaller motors (up to a bore diameter of approximately 16") have semi-closed slots with coils of round wire fed into the slots through the slot openings. The coils are usually round-end or flat-diamond. The larger motors have open slots and use preformed diamond windings of either round wire or rectangular wire, the trend being to rectangular wire for all large motors. Normally, lap windings are used in polyphase stators, but some wave windings also have been made. Wave windings are generally used in the rotors of wound rotor induction motors.

While the chain windings of single-phase motors consist of coils of different spans, the 2-layer windings of polyphase motors consist of coils of equal span. In single-phase motors, part of the coils have a span nearly equal to the pole pitch and part of the coils have a span much smaller than the pole pitch. In polyphase motors, the coils have equal spans, but, as mentioned previously, the span must be equal to or less than the pole pitch, i.e., they may be full-pitch or fractional-pitch.

Most polyphase induction motors have *integral-slot windings,* i.e., the number of slots per pole per phase, spp, is an integral or whole number. In this case, all pole-phase groups of the winding have an equal number of single coils.

The statements made above about the windings of polyphase motors apply also to the stator windings of synchronous motors and generators. However, synchronous motors and generators with a large number of poles usually have *fractional-slot windings,* i.e., the number of slots per pole per phase, spp, is a fractional number. In this case, the number of single coils is not the same for all pole-phase groups of the winding. In the following chapters, the different kinds of windings will be treated in detail.

CHAPTER 2

TYPES AND INSULATION OF POLYPHASE WINDINGS

The polyphase windings are usually wound in 2 layers, i.e., in each slot there are 2 layers of conductors separated from each other (Fig. 1-4). These windings can be divided into 2 broad classes, lap windings (Fig. 1-13) and wave windings (Fig. 1-14). In both cases, all coils have the same span. In the lap winding, there is usually one coil side in each layer, while in the wave winding the number of coil sides in each layer can be larger than one. The total number of coils in the lap winding is, therefore, equal to the number of slots while in the wave winding, it can be larger than the number of slots. The lap winding is used in the stators of polyphase induction motors and synchronous machines. It is also used in the rotors of the smaller induction motors with wound rotors. The wave winding is used mainly in the rotors of the larger induction motors with wound rotors. In the following, the lap winding will be considered first, followed by the wave winding.

A. LAP WINDINGS

Three factors are important in the consideration of polyphase windings. These are: the number of poles, the number of phases, and the number of slots. The number of slots determines the number of single coils. The number of poles multiplied by the number of phases determines the number of pole-phase groups (Eq. 1-4). Consequently, the number of slots divided by the number of pole-phase groups determines the number of slots per pole-phase group, or spp, i.e.,

$$\begin{matrix}\text{No. of slots per}\\ \text{pole-phase group}\end{matrix} = \text{spp} = \frac{\text{No. of slots}}{\text{No. of poles x No. of phases}} \qquad (2\text{-}1)$$

For example, a 4-pole, 3-phase stator with 48 slots has

48 single coils,

4 x 3 = 12 pole-phase groups, and

$\frac{48}{4 \times 3}$ = 4 slots (single coils) per pole-phase group = spp.

While the number of pole-phase groups is always an integer, i.e., a whole number, the number of slots per pole-phase group may be either an integer or a fractional number. In the latter case, the number of slots (single coils) is not the same for all pole-phase groups.

2-1. Types of Lap Windings. There are 3 common types of lap windings:

Round-end winding (Fig. 1-10).
Flat-diamond winding (Fig. 1-11).
Pulled or spread-diamond winding (Fig. 1-12).

The first two are used in smaller motors with semi-open slots and round wire. They are mush wound. The third type is used in medium-sized,and larger machines with semi-closed and open slots and round as well as rectangular wire. Coils with rectangular wire are always pulled or spread coils.

(a) Round-end Winding. The coils of this winding are wound on a mould. If a gang mould, as shown in Fig. 2-1, is used, all coils of a pole-phase group can be made in succession with a single conductor, which may consist of one or more parallel strands. The perimeter of the mould is best determined by a trial with a single strand of wire looped around the stator teeth in the same position that the finished coil is to occupy. Instead of a mould, wire finishing nails driven into the bench can be used to wind round-end coils. The wires are fed into the

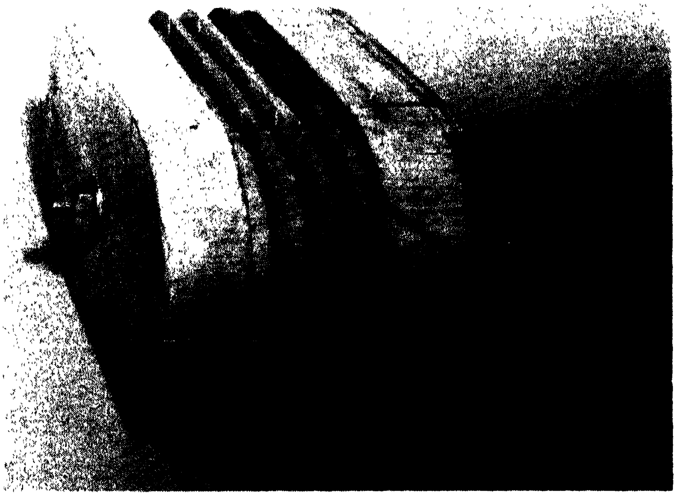


Fig. 2-1. Gang mould for round-end coils

slots through the slot openings one or two at a time. Guides to cover the sharp edges of the slots may be necessary while feeding the wires into the slots.

(b) Flat-diamond Winding. As in the case of the round-end winding, this winding can be wound on a gang mould (Fig. 2-2a), using one continuous wire for each pole-phase group. The wire may consist of one or more strands and may be fed through the slot openings, using guides to protect the wire insulation from being injured by the sharp edges of the teeth. The flat-diamond coils are also wound automatically, using a 6-rod shuttle as shown in Fig. 2-2b.

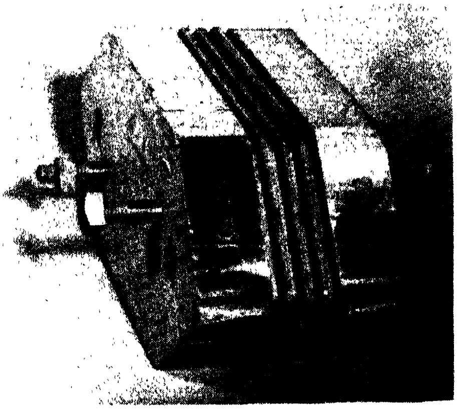


Fig. 2-2a. Gang mould for flat-diamond coils.

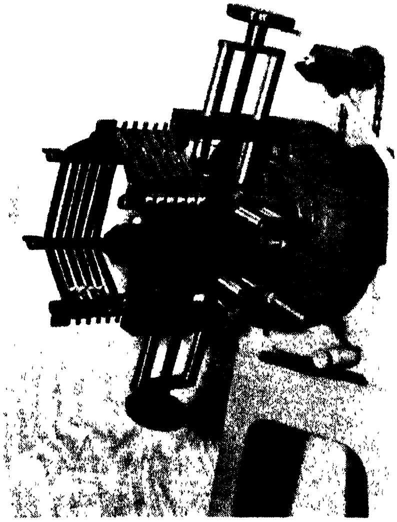


Fig. 2-2b. 6-rod shuttle for winding flat-diamond coils

The dimension m in Fig. 2-2c of the flat-diamond coil is important; making it too small gives a winding which is too tight, whereas making it too large decreases the distance between winding and end brackets. The radius r at the diamond points and other bends is usually 1/4". The coil thickness h is the thickness of the center block of the mould on which the coil is wound; it is approximately 40% of the depth of the slot.

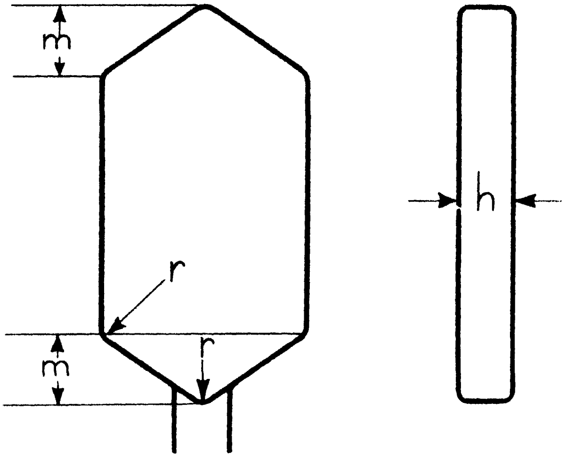


Fig. 2-2c. Flat-diamond coil

(c) Pulled or Spread-diamond winding. Coils of this kind are first wound into loops and then formed by a puller or spreader. The loop is wound around 2.rods (Fig. 2-3a), or on an adjustable shuttle (Fig. 2-3b). In Fig. 2-3c,(a) is the starting lead, (b) the finishing lead, (c) the bottom slot section, and (d) the top slot section.

Fig. 2-3a. 2-rod fixed shuttle for winding spread-diamond coils

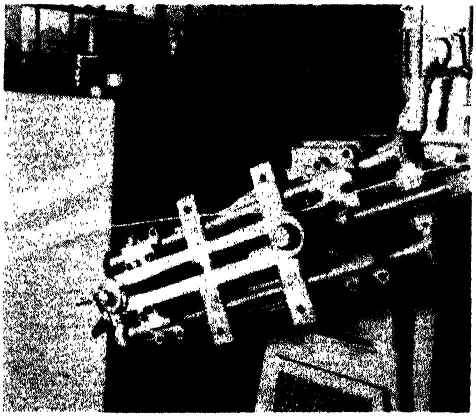
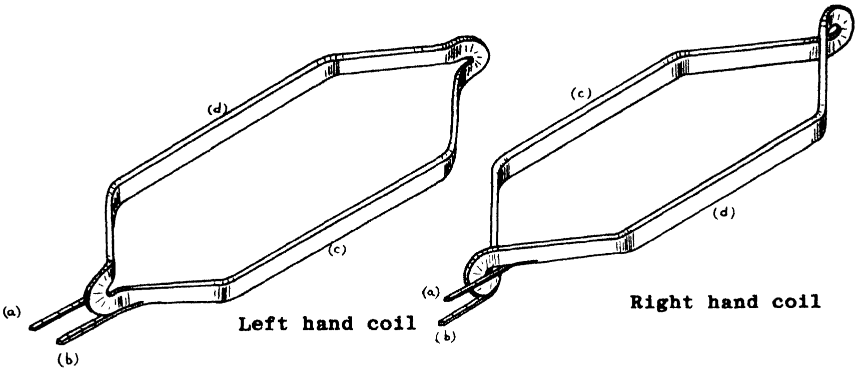


Fig. 2-3b. 2-rod adjustable shuttle for winding spread-diamond coils



Left hand coil **Right hand coil**

Fig. 2-3c. Pulled or spread coil

2-2. Throw Coils. Consider Fig. 2-4 which represents a 4-pole, 3-phase winding with 24 slots and a coil span equal to 5 slot pitches (1-6). The winder will place first the bottom coil side of coil 1 in the bottom of slot 1, but will leave the top coil side of this coil outside slot 20, resting it on the core; he cannot put this coil side in the top of slot 20, since there is not yet a bottom coil side. The same will be done with coils 2, 3, 4, and 5, leaving the top coil sides for slots 1 to 5 resting on the core. Starting now with coil 6, the bottom coil side will be placed in the bottom of slot 6 and the top coil side in the top of slot 1, which has already a bottom coil side.

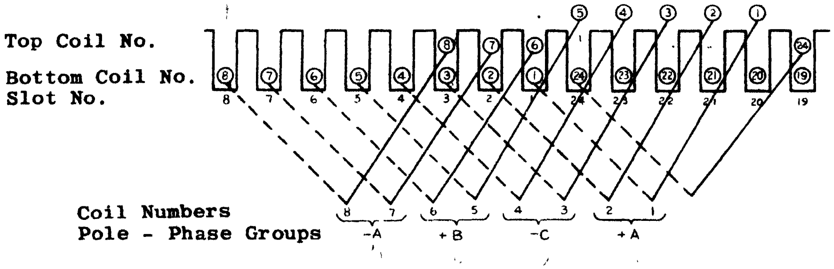


Fig. 2-4. 4-pole, 3-phase winding with 24 slots
Throw-up (top-to-bottom) winding

Progressing in the same way, the coils 7, 8, 9, etc. will be placed in their respective slots, filling out the bottom of the slots 7, 8, 9, etc. and the tops of slots 2, 3, 4, etc., until the winding reaches slot 24. When the bottom coil side is placed in slot 24, the top coil side is placed in the top of slot 19.

Now the top coil sides of coils 1, 2, 3, 4, and 5 which rested on the iron can be placed in the top of slots 20, 21, 22, 23, and 24.

The first coils 1 to 5 are called throw coils. The number of throw coils is equal to the coil span expressed in slot pitches. In Fig. 2-4 the coil span is equal to 5 slot pitches (1-6) and therefore the number of throw coils is equal to 5. The method of winding shown in Fig. 2-4 is called throw-up or top-to-bottom winding. The throw-up connection is used for pulled coils as well as for round-end and flat-diamond coils. Fig. 2-5 shows the throw-down or top-to-top and bottom-to-bottom winding. In this case, both coil sides of the throw coils are placed in the bottom of the slots, i.e., coil 1 is placed in the bottoms of slots 1 and 20, coil 2 in the bottoms of slots 2 and 21, and so forth. Then starting with coil 6, the coil sides go from the bottom to the top, as in the case of the throw-up winding. After the last bottom coil sides 15, 16, 17, 18, and 19 are placed in the bottoms of the slots 15, 16, 17, 18, and 19, there remains open the tops of slots 15 to 24 to be filled by the last 5 coils - 20, 21, 22, 23, and 24, which are top-to-top coils.

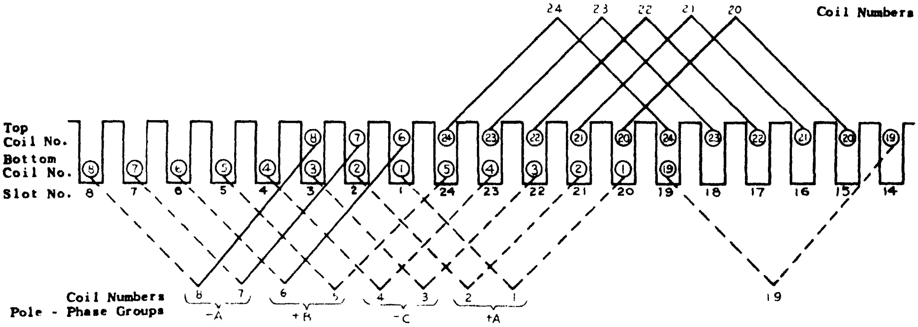


Fig. 2-5. 4-pole, 3-phase winding with 24 slots.
Throw-down (top-to-top or bottom-to-bottom) winding

The throw-down connection is used only for the round-end and flat-diamond winding, but not for the pulled winding. It is especially convenient for two-pole motors, where the span is large with respect to the diameter and the large number of throw coils interferes with the winding process.

2-3. Straight-up Wound Pulled Coils and Cross-over Pulled Coils. When the wire space of the shuttle widthwise is filled only by one conductor or, in general, when there is only one conductor in the width of the slot, each succeeding turn is built up on top of the preceding one, making a "straight-up" wound coil. When the number of conductors in the width of the slot is larger than one, as for example in Fig. 2-6, the wire crosses over itself in going from the finish of one layer to the start of the next. In Fig. 2-6, each layer contains 4 conductors. Turn 1 in the first layer is the starting lead, and turn 16 of the fourth layer is the finishing lead. A cross-over occurs in going from turn 4 to turn 5, from turn 8 to turn 9, and from turn 12 to turn 13. For mechanical reasons, more than for electrical ones, the end cross-overs must be insulated during the winding. Furthermore, attention must be paid to the fact that in cross-over coils the voltage between neighboring turns is higher than in straight-up wound coils. In a straight-up wound coil, the peak value of the voltage between two adjacent conductors is equal to the maximum voltage of one turn, i.e., to the phase voltage multiplied by $\sqrt{2}$(= 1.414), and divided by the number of series turns per phase

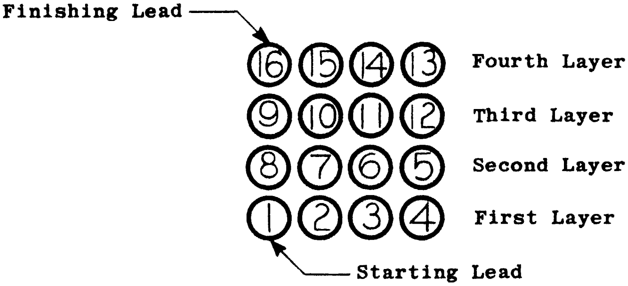


Fig. 2-6. Cross-over coil

$$\text{Maximum voltage per turn} = \frac{1.414 \times \text{Phase voltage}}{\text{Series turns per phase}} \qquad (2\text{-}2)$$

It must be remembered that in the 3-phase star connections, the phase voltage is equal to the line voltage divided by $\sqrt{3}$(= 1.731); in 3-phase delta connections, the phase voltage is equal to the line voltage. The number of series turns per phase is

$$\text{Series turns per phase} = \frac{\text{No. of coils} \times \text{Turns per coil}}{\text{No. of phases} \times \text{No. of parallel circuits}} \tag{2-3}$$

(No. of parallel circuits = One, for the series connection)

Consider now Fig. 2-6. The voltage between turns 1 and 2, or 2 and 3, or 4 and 5, is that of one turn, just as in the straight-up wound coil; the voltage between turns 3 and 6 is 6 - 3 = 3 times the voltage of one turn, and the voltage between the first turn of the first layer (turn 1) and the finishing turn of the second layer (turn 8) is 8 - 1 = 7 times the voltage of one turn. To meet these higher voltages between adjacent turns, either heavier wire insulation or insulation strips between the single layers may become necessary.

Cross-over coils can be sectionalized, i.e., a number of single conductors are wound straight up, in sections, the sections separately insulated and then connected in series. Fig. 2-6a shows a 2-section cross-over coil with 10 turns arranged

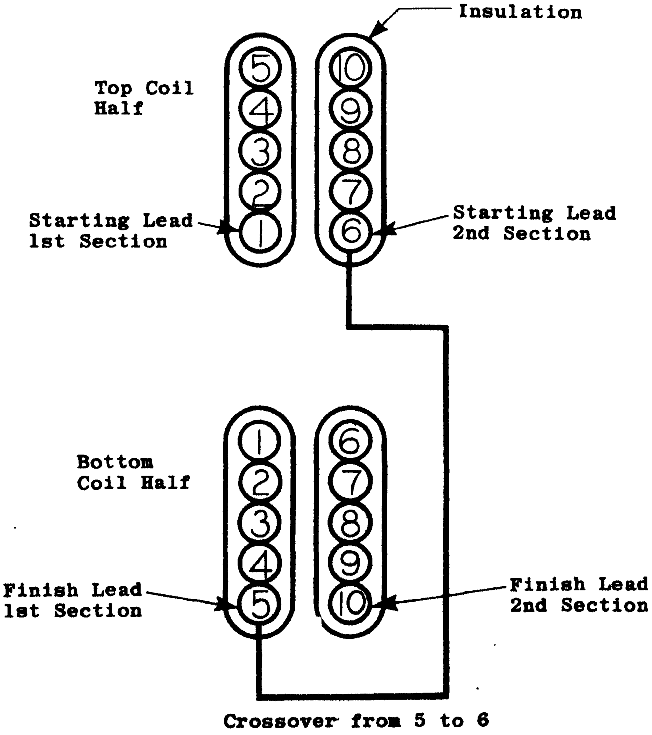


Fig. 2-6a. Two-section cross-over coil

2 wide by 5 deep. The 2 sections are side by side, and each section is insulated separately. Both sections are connected by connecting the finishing lead of the first section with the starting lead of the second section. The connection is made at the diamond point of the coil with a soldered sleeve joint, and the finishing lead is bent across the nose of the coil. The voltage between sections, at any point, is equal to the volts per turn multiplied by the turns per section, since between any pair of conductors, for example, the conductors 3 and 8, there is always the total number of turns of the section. Sectionalized cross-over coils are used when the number of turns of the coil is large and the width of the slot is large in comparison to its depth.

2-4. Stranding of Rectangular Conductors in Spread Coils. Conductors of large cross-section normally are divided into strands for mechanical as well as for electrical reasons. The mechanical reason is to make the coil flexible, i.e., easy forming. The electrical reason is to avoid parasitic currents in the conductors which increase the heating of the copper. These parasitic currents are due to the following: the current which flows in the conductors causes a magnetic flux across the slots going from one slot wall to the other (Fig. 2-7). Since this flux is produced by an alternating current, it changes its magni-

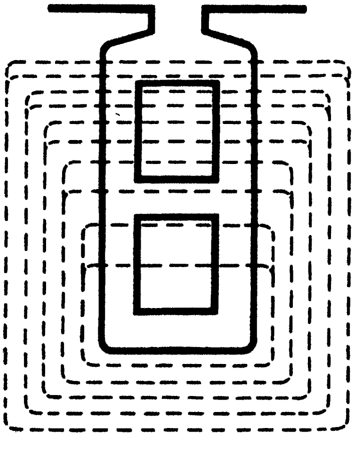


Fig. 2-7. Magnetic flux across a slot.

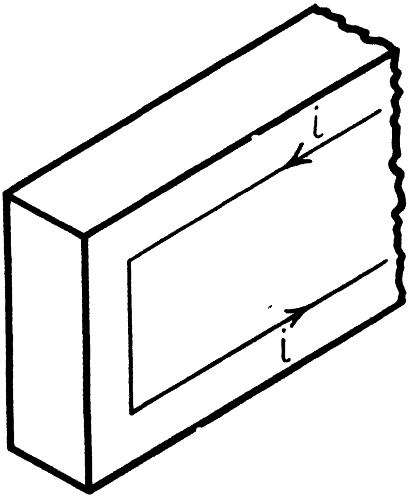


Fig. 2-8. Parasitic currents in the conductor

tude and induces emf's and currents in the copper, as indicated in Fig. 2-8. It can be seen from this figure that nothing will be changed in the parasitic currents if the stranding is made parallel to the slot walls (Fig. 2-9). Stranding for electrical reasons is effective only if it is made perpendicular to the slot walls, i.e., the stranding of the conductors of Fig. 2-7 should be made as shown in Fig. 2-10.

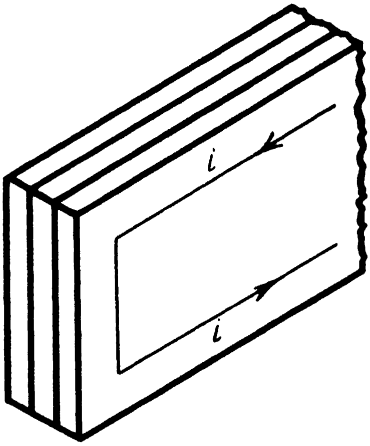


Fig. 2-9. Stranding parallel to slot walls. This stranding is not effective.

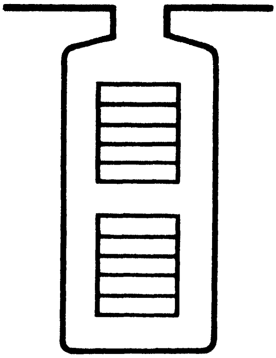


Fig. 2-10. Stranding perpendicular to slot walls. This strand- is effective.

When conductors are stranded for electrical reasons, the individual strands must be insulated. In the arrangement shown in Fig. 2-11, only a part of the strands are insulated. This figure shows a slot with 6 conductors, each conductor consisting of 8 strands. The narrow strands are bare, having the same height as the wide strands with insulation; (this arrangement is commonly known as the brick winding). The additional copper losses[1] due to the parasitic currents are proportional to the height of the conductor, to the height of each strand, and to the frequency of the line current. The thickness of the strands is made as small as practical.

Fig. 2-12 shows different ways of dividing a conductor into 2 strands. In Fig. 2-12 the strands are arranged widthwise; in

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[1] Electric Machinery, Liwschitz-Garick and Whipple, Vol. I, pp.231-236.

Fig. 2-13 they are arranged depthwise. There are 3 conductors in the coil side. From a mechanical point of view, preference should be given to the arrangements shown in Fig. 2-13a and 2-13b. From an electrical point of view, the arrangement of Fig. 2-12b and 2-13b will have the smallest additional losses due to parasitic currents.

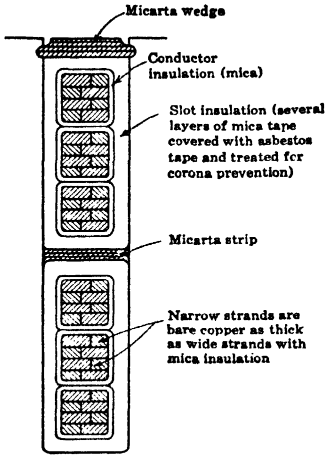

Micarta wedge
Conductor insulation (mica)
Slot insulation (several layers of mica tape covered with asbestos tape and treated for corona prevention)
Micarta strip
Narrow strands are bare copper as thick as wide strands with mica insulation

Fig. 2-11. Brick winding

2-5. Starting and Finishing Lead. In winding spread coils, the starting lead, i.e., the lead first fastened to the shuttle when starting to wind the coil, is always brought out from the center

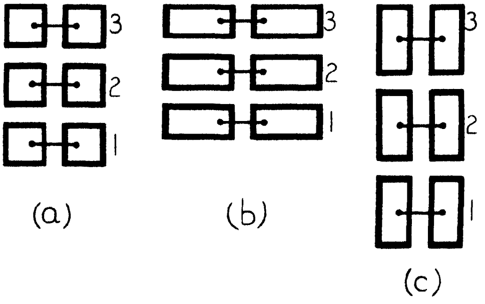


Fig. 2-12. Different ways of dividing a conductor in 2 strands widthwise.

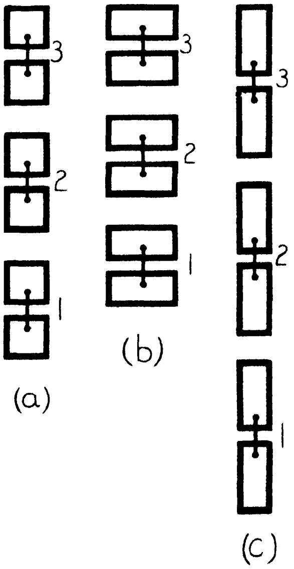


Fig. 2-13. Different ways of dividing a conductor in 2 strands depthwise

of the loop, while the finishing lead is brought out from the top of the loop. Both leads are brought out at the end of the loop.

Left-hand and Right-hand Coils. Arrangement of Leads. With respect to the position in the slot, the coil section which lies nearest the air gap is called the top coil side, while the other coil section which lies at the bottom of the slot is called the bottom coil side. When the winder faces the lead end of the stator and the top coil sides are at his left, the coils are designated as left-hand coils, otherwise, they are designated as right-hand coils. Only left-hand coils will be considered in this book (see Fig. 2-3c and Fig. 6-1).

Two lead arrangements are possible: leads may be on the top at the diamond (Figs.2-14a and 2-14b) or leads may be on

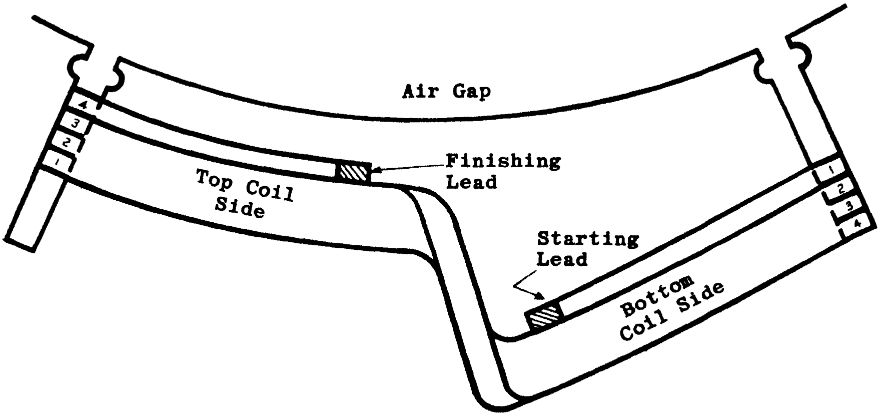


Fig. 2-14a. Left-hand coil with leads on top

the bottom at the diamond (Fig. 2-15a and 2-15b). The leads are on the left when spreading. If, when spreading, the leads are on the bottom, the lead arrangement (Fig. 2-14a) will result; on the other hand, if, when spreading,the leads are on the top, the lead arrangement (2-15a) will result. Figs. 2-14a to 2-15b show the main lead arrangements, namely, leads on top and leads on bottom. In Figs. 2-14b and 2-15b, the leads are brought straight out. The leads also can be bent away from the gap (Fig. 2-16). Further, the starting lead can be free or fastened to the nose of the coil.

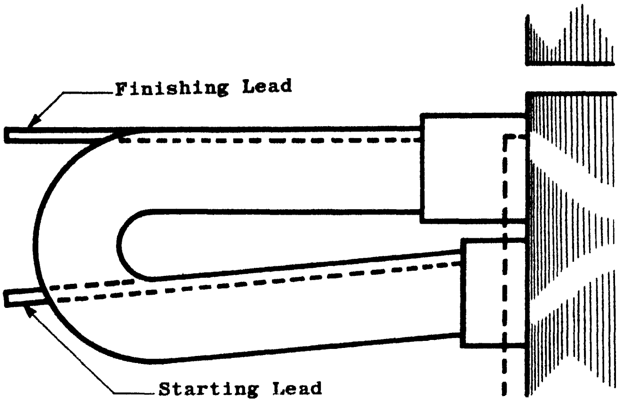


Fig. 2-14b. Leads on top.

Straight-out leads are used in windings for low voltages (up to 600 volts), or where ample space is available between the coil ends and the end bells. With the leads on the bottom (Fig. 2-15a), the leads are farther away from the air gap. For higher voltages, the lead arrangement (Fig. 2-16) with bent leads at the top is preferred, since it permits a safe fastening of the leads to the nose of the coil.

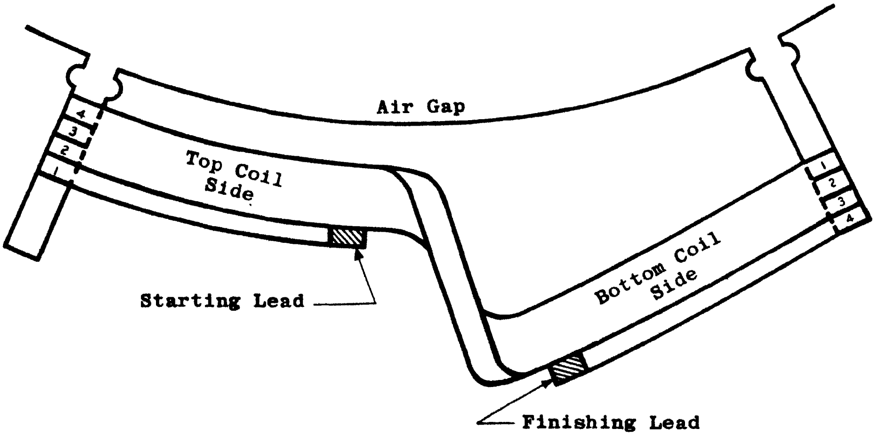


Fig. 2-15a. Left-hand coil with leads on bottom

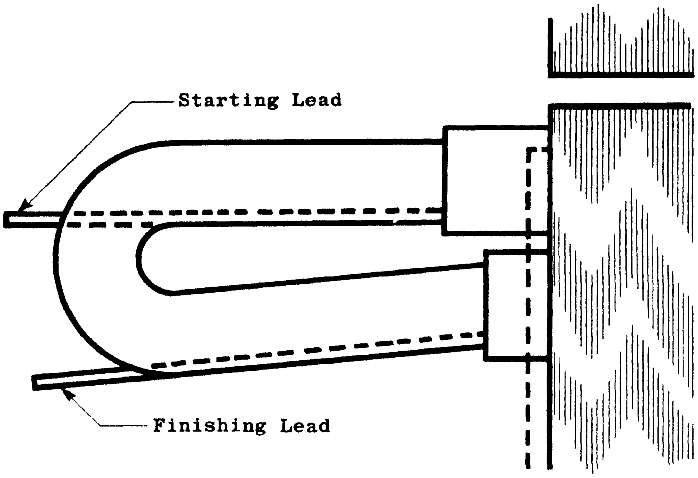


Fig. 2-15b. Leads on bottom.

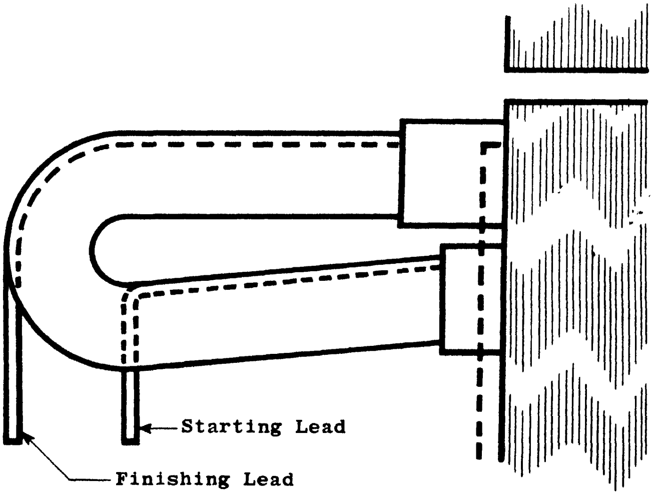


Fig. 2-16. Leads bent away from gap

2-6. Insulation of Conductors, Slots, and End Windings. The different kinds of insulating materials used in electric machines are divided into 3 classes specified by AIEE on the basis of NEMA standards. Recently a fourth class has been added on a trial basis. These 4 classes are given in Table 2-1. The same table contains the limiting temperatures which cannot be exceeded without impairing the life of the material. A guide for stator rewinding material is shown in Table 2-9.

In the following, the conductor insulation, strand insulation, ground insulation, end-winding insulation, and binder insulation, will be considered.

Conductor Insulation. On round and small rectangular or square wire, the conductor insulation is applied before the coil has been formed; on straps or large rectangular or square conductors the insulation is applied after the coil has been formed, or in the process of forming the coil. The materials used for conductor insulation are given in Table 2-2. Tables for bare and insulated round, square and rectangular copper wire are given at the end of the book.

The thickness of the conductor insulation depends upon the voltage between turns (see Art 2-3). In general this voltage should not exceed 12 volts for SCC, SFG or enamel, and 25 volts for DCC, DFG or SCE. When the turn voltage is greater than 25 volts, but less than 40 volts, either TCC or TFG can be used, or a certain amount of insulation can be added to the normal DCC or DFG conductor insulation resulting in a conductor insulation equivalent to TCC or TFG. This additional insulation can be either cotton or glass tape, or paper or mica strips applied throughout the coil. For values of turn voltage greater than 40 volts, the trend is to use additional insulation in the form of mica tape. For values up to 70 volts one serving of mica tape half lapped is used and for values up to 120 volts, two servings of mica tape are used.

Strand Insulation. When conductors with larger cross section are stranded (see Art. 2-4), the strand insulation is cotton, asbestos, or glass, with a thickness of 0.008" to 0.010" for both sides.

Ground Insulation. This is the insulation applied to the slot portion of the coil. It serves to prevent the breakdown of the insulation to ground (core iron) and must, therefore, have sufficient dielectric strength. The materials used for ground insulation are given in Table 2-3. The ground insulation will be considered separately for semi-closed and for open slots.

Ground Insulation of Semi-closed Slots. Some arrangements of ground insulation, i.e., of cell and seal at the slot opening for semi-closed slots, is shown in Fig. 2-17. The thickness of the cell is 0.020" to 0.030". Fishpaper and varnished cloth are often used as cell material for Class A insulation, the cloth being cemented to the fishpaper and the latter laying outside against the iron. Combinations of mica and fishpaper, or mica and glass cloth,are used for Class B insulation,the mica usually being protected on both sides. Combinations of glass and mica treated in silicone varnishes are used for Class H insulation.

In order to prevent tearing the edges of the cells, a selvage of thin Scotch tape or cotton tape is applied to each edge of the cell. For this purpose, the cell material is cut into long strips as wide as the length of the cell, and the selvage is put on both edges of the strip, which is then cut into pieces of proper width.

In the arrangement Fig. 2-17a used for small motors, the wedge consists of cell material or paper;in Figs.2-17b and 2-17c, the wedge is made of wood, giving a tighter seal than that of Fig. 2-17a. Fig. 2-17d is a combination of Fig. 2-17a and Fig. 2-17b and is used for windings of higher voltages (up to 600 volts) exposed to dirt. The strip in the middle of the slot of Figs.2-17a to 2-17d is used to separate the upper coil side from the lower.

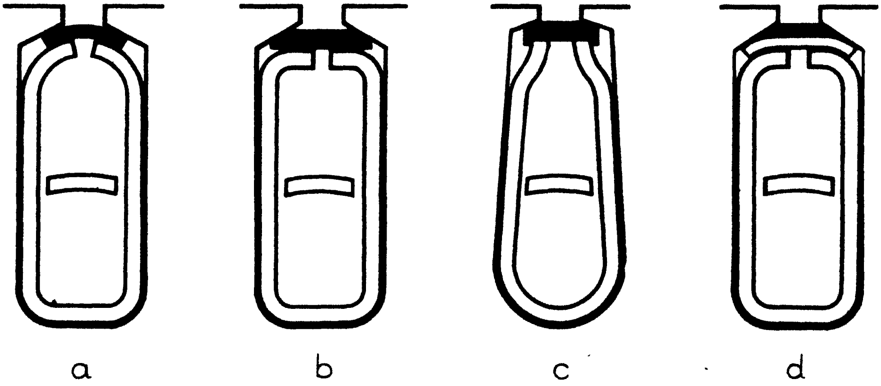


Fig. 2-17. Arrangements of slot (ground) insulation for semi-closed slots

Ground Insulation of Open Slots. Contrary to the windings in semi-closed slots where the ground insulation is not a part of the coil, the ground insulation of windings in open slots is applied directly to the coils and is a part of the coil. It consists of a wrapper of which the material and number of turns depend on the voltage. Before spreading the coil, a temporary binder must be applied. This binder has 2 functions: it binds the conductors tightly together to obtain the proper shape of coil; and it protects, mechanically, the strand or conductor insulation. This binder is usually 0.005" to 0.010" thick and is applied without lap or with space between turns. After spreading, the coil is then impregnated with varnish for voltages below 3500 volts or with asphalt for higher voltages. The varnish-impregnated coils are drained after dipping and then baked in an oven with forced ventilation for 6 to 10 hours at 115 to 120^{o} C. Class H coils impregnated with silicone varnish are baked in high temperature forced ventilation ovens in temperatures ranging from 165 to 250^{o} C. One dip is applied for voltages below 1200 volts, and 2 dips for voltages between 1200 and 3500 volts. The asphalt impregnation occurs under vacuum and pressure.

The material of the wrapper, its thickness, and number of turns for the different voltage and insulation classes are given in Table 2-4. For 11,000 and 13,200 volts, no wrapper is used. Instead, a continuous mica tape is applied over the slot portion as well as over the end windings to build up a wall thickness of 0.145" and 0.190", respectively. Then, an over-all binder of 0.010" or 0.015" glass tape or asbestos tape is used. Special varnishes to minimize the effects of corona are applied to the slot portions for high voltage coils.

End-winding Insulation. The end-winding insulation is usually applied in the form of tape. The materials used for the end-winding insulation are given in Table 2-5. The end windings of mush coils are either taped in the process of inserting the coils into the slots or are left untaped. In the former case one layer of 0.007" thick cotton tape can be applied for Class A insulation, 0.007" to 0.010" thick glass tape or glass and mica tape for Class B insulation,and 0.007" to 0.010" thick glass tape or glass and mica tape silicone treated for Class H insulation. When the coils are untaped, triangular pieces of treated cloth are inserted between all coil ends or at least between the coils belonging to different phases.

The end windings of coils in open slots are taped in one or several layers, depending upon the voltage. For Class A insulation, cotton tape or bias-cut varnished cloth tape is used; for Class B insulation,mica tape is applied; and for Class H insulation silicone glass mica tape is applied. The number of layers of the material and its thickness are given in Table 2-6. For 11,000 and 13,200 volts, the end-winding insulation is the same as the ground insulation.

Finishing and Varnishing the Coils. To finish mush coils, 2 to 4 coats of varnish are applied to the wound stator, depending on the class of insulation and voltage. Each coat is baked on. Care must be taken that the varnish penetrates the coils at the ends as well as in the slot portions.

Coils in open slots get a finishing tape before the varnish treatment is applied. The material and thickness of the tape, as well as the number of dippings in varnish, are given in Table 2-6. Draining and baking follow each dipping.

Lead Insulation. While winding mush coils, tubing or sleeving is applied to the leads. For Class A insulation, the material is cotton saturated with varnish. Glass sleeving is used for Class B insulation and glass sleeving silicone-treated is used for Class H insulation. The tubing or sleeving begins 1 1/2" to 2" within the coil. In group (gang) wound coils, tubing or sleeving also has to be applied to the cross-overs. In a 2-coil group, for example, 3 tubes or sleeves are necessary. On cross-overs, tape is usually wrapped on top of the tubing or sleeving. The starting and finishing ends of a pole-phase group usually serve as jumpers from group to group and must be made long enough to be used for this purpose. Their length should be equal to $\frac{3.14\ D'}{2p} + 2$ inches, where D' is the diameter at which the leads lie, and p the number of poles.

The leads of coils in open slots are either tied to the coil or left loose. At higher voltages, attention must be given to the starting lead, since it crosses the diamond point. When the leads are tied to the coil, strips of insulating material are placed between the leads and coil. Up to 600 volts, a piece of 0.010" treated material is used under the starting lead. At voltages from 600 to 2500 volts, one strip of mica and fishpaper, 0.012" to 0.015" thick, is placed under each lead. At voltages from 2500 to 6600 volts, 2 strips of 0.012" to 0.015" mica and fishpaper are applied to each lead. For Class H insulation, silicone-treated mica tape is used to protect the starting lead in the diamond point of the coil. In all cases, the leads must be firmly tied to the coil by a cord or tape and insulated with the same material and at the same time as the end windings. The number of layers or servings is 2 for voltages up to 2500; 3 for voltages from 2500 to 4500 volts; and 4 for voltages from 4500 to 6600 volts.

When the leads are loose, tubing or 0.007" cotton tape half-lapped can be used for voltages up to 600 volts. For voltages, 600 to 3500 volts, 3 layers of half-lapped 0.010" bias-cut treated cloth tape, plus one layer of half-lapped 0.007" cotton tape, can be used. For voltages 3500 to 4500 volts, 4 layers have to be used, and for voltages 4500 to 6600 volts, 6 layers of the same material as before, plus one layer of 0.007" cotton tape, half-lapped. For Class B insulation, 0.006" mica tape instead of treated cloth, and 0.007" glass tape instead of cotton, have to be applied. For Class H insulation, 0.004" silicone glass mica tape and 0.007" silicone glass tape have to be used. In open-slot coils, either all leads have standard length (3" beyond the edge of the coil) and cables are used for jumpers, or the leads are made long enough to be used for jumpers. In the latter case, one half of the coils belonging to a phase have long starting leads and 3" long finishing leads, while the other half of the phase coils then have long finishing leads and 3" long starting leads. This arrangement saves copper. The length of the jumper must be equal to $\frac{3.14\,D'}{2p} + 3''$ where D' is the diameter at which the leads lie. If cable is used for jumpers, then the length of the cable must be $\frac{3.14\,D'}{p} + 3''$.

Insulation of Stub Connections, Jumpers, and Tie-rings. In larger machines, the end windings must be braced in order to avoid distortion which may be produced by large currents (short-circuit current in a generator, starting current in a motor). For this purpose, one or two rings are placed on the end windings, and the latter tied to the ring (or rings) by twine. The ring must be insulated and the insulation applied is the same as for stub connections and jumpers. The thickness of the insulation depends upon the voltage. It is 0.040" for voltages up to 600 volts; 0.060" for voltages 600 to 2500 volts; 0.070" for voltages 2500 to 3500 volts; 0.080" for voltages 3500 to 4500 volts; 0.100" for voltages 4500 to 6600 volts; 0.140" for voltages 6600 volts to 11,000 volts; and 0.160" for voltages 11,000 to 13,200 volts. The insulation for Class A consists of one layer of 0.007" cotton tape half-lapped, of a number of layers (corresponding to the voltage) of 0.010" black bias-cut varnished cloth tape 1" wide, and of a finishing layer of 0.007" cotton tape (half-lapped). For Class B insulation, 0.006" mica tape is to be used instead of the varnished cloth tape, and 0.007" glass tape instead of cotton. For Class H insulation, silicone glass mica tape and silicone glass tape are to be used instead of the conventional mica and glass tapes. Before applying the insulation, the metal must be cleaned and brushed with a good baking varnish. The first layer of insulation has to be applied while the varnish is wet. Varnish has to be applied after each layer. The finished insulation must get the same number of coats as the insulated coils get (see Table 2-6).

Mechanical Clearances. An important factor for windings of electric machines is the creepage distance, i.e., the distance which a current must creep across insulation or through the air, or through a space filled with dirt, in order to produce a fault to ground or to another phase. The clearances for semi-closed, as well as for open slots, are given in Table 2-7. The significance of the letters A, B, etc., can be seen from Fig. 2-18. Except in small motors for low voltages, the top cell (or wrapper) is longer than the bottom cell (or wrapper). In the last column, the distances between the end windings of neighboring coils are given for different voltages. These distances are necessary with respect to the air flow between the end windings. The higher the voltage is, the heavier is the insulation, and the more air is necessary to carry away the heat developed in the conductors.

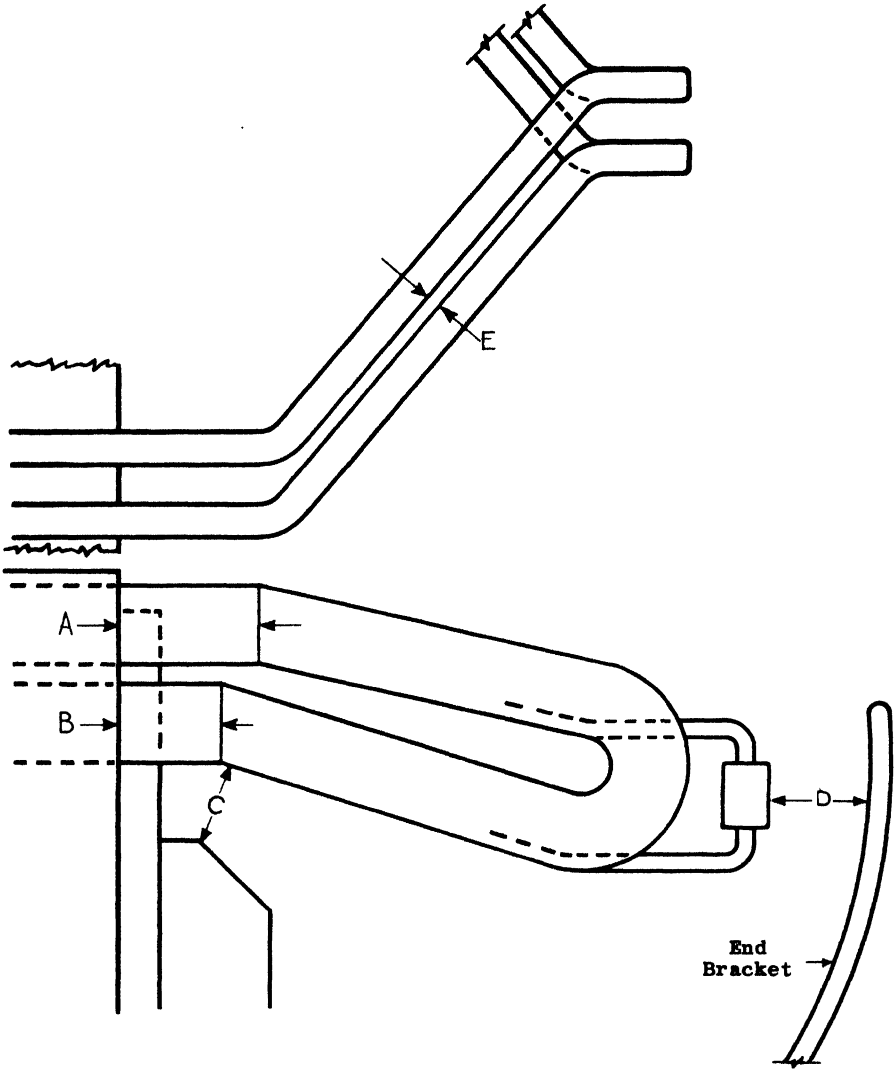


Fig. 2-18. Creepage distances or mechanical clearances

B. WAVE WINDINGS

Wave windings are usually used in the rotors of wound rotor induction motors. Sometimes they are used in the stators also. However, in this discussion, the wave windings will be described from the viewpoint of rotor application.

2-7. Insulation of Slots and End Windings. The lap windings considered previously and also the wave windings considered here are 2-layer windings. The conductors are made up of straps with one turn per coil, open at the front end (Fig. 2-20). The number of conductors per slot per layer may be one or more than one. Fig. 2-19 shows the arrangement for 1 to 4 conductors per slot per layer. Since each conductor pair represents a coil, the number of coils of the wave winding is equal to the number of conductors per slot per layer times the number of slots. In the lap winding,the number of coils is equal to the number of slots.

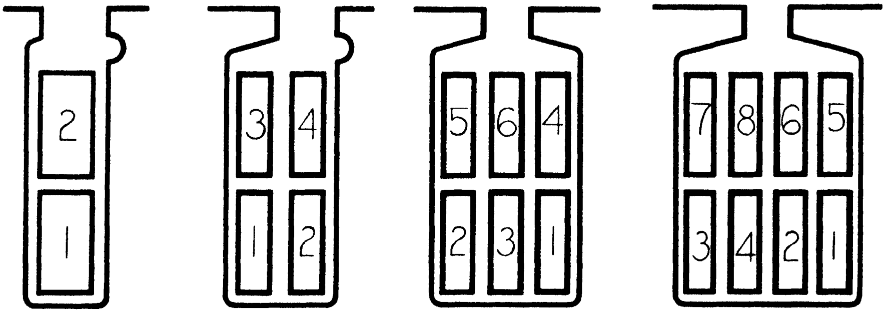


Fig. 2-19. Different conductor arrangements in rotors with wave windings

The slots are semi-closed. Since the coils are inserted through the slot openings, the latter must be at the side of the slot when the number of conductors per layer is 2. The conductors of the lower layer are placed in the slot first. The order in which the conductors of the lower and upper layer are put into the slot is indicated by the number 1-2, 1-2-3-4, etc., in Figs. 2-19 and 2-20. While the upper conductors are inserted into the slot, their lower conductors already lie in another slot which is a pole pitch or approximately a pole pitch apart from the slot in consideration.

The coils lying side by side in each layer are connected in series. Their ends are joined by clips in the form of a figure 8. The laying out of wave windings and their connection diagrams will be discussed in Chapters 6, 7, and 8. Only the insulation of the wave windings will be described here.

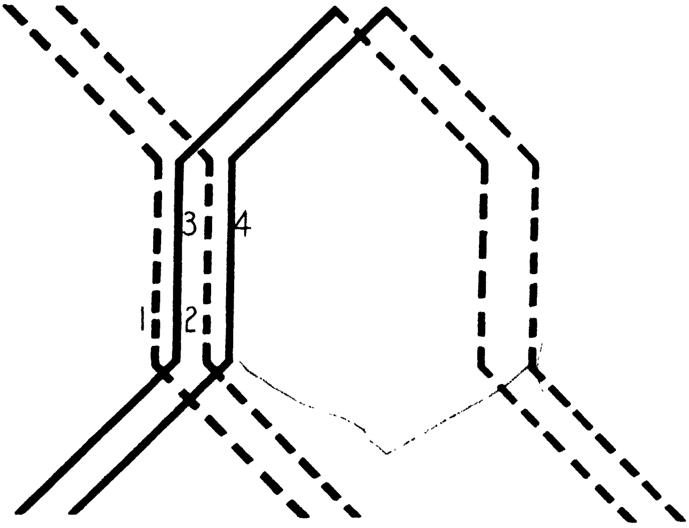


Fig. 2-20. One-turn wave winding

Ground and End-winding Insulation. The ground insulation of a wave winding consists of a wrapper on the slot portion and of tape on the end windings. The material used, its thickness, and number of layers are given in Table 2-8. The treated cloth tape on the end windings is half-lapped. The finishing tape is spaced on the slot portion and half-lapped on the end windings. If the wrapper material has grain, the latter must run parallel with the length of the wrapper.

The materials specified in Table 2-8 refer to Class A insulation. For Class B insulation, mica on a paper base is used for the wrapper and mica tape for the end windings. Mica tape is also used as ground insulation instead of the wrapper in some cases. For Class H insulation, silicone mica glass is used for the wrapper and silicone glass mica tape can be used for ground insulation on the slot portion and also for the end windings. The finishing insulation for Class A is 0.007" half-lapped cotton tape on the end windings, and butt-lapped on the slot portion. The finishing insulation for Class B is glass tape treated in ordinary varnish and, for Class H insulation, the finishing tape is silicone glass tape. Additional insulation has to be provided for the phase coils.

The varnish treatment of the coils consists of one dipping and baking for voltages below 1200 volts, and 2 dippings and bakings for voltages higher than 1200 volts. The wound rotor, for all voltages, must get one additional dipping and baking and then a spraying with an air drying varnish. The baking time is 4 to 6 hours at 110° C for the coils, and 12 to 36 hours (depending on the diameter) at 115 to 125° C for the wound rotor with Class A or Class B windings. Temperatures of 165 to 250° C are to be used for wound rotors having Class H windings.

Before putting the coils into the slots, fishpaper cells, 0.010" to 0.015" thick, are inserted into the latter, depending on the available space. The cells should project about 2" above the iron, in order that the projecting parts of the cells be flexible. A fiber strip is placed in the bottom of the slot between iron and cell to prevent the cell from being damaged by high laminations or burrs during the process of winding and while pressing the coils against the bottom of the slot by the wedges. The fiber strip should be 1/2" longer than the core. For Class B coils, fishpaper cells are also used in the slots before inserting coils. However, a canvas base bakelite strip is used at the bottom of the slot instead of the fiber strip used in Class A windings. For Class H insulation, it is preferable to omit a slot liner, but if one is used it must be of silicone-treated mica and glass. The insulation at the bottom of the slot must be mica or melamine.

Separation of Upper and Lower Layer. A fiber strip, for Class A windings,has to be placed between upper and lower layers in the slot portion which goes from the bend on one side of the rotor to the bend on the other side. The separator between the upper and lower layers in the end windings consists of 2 or more strips of treated duck cloth, each about 0.030" thick, or of 2 or more strips of varnish-treated asbestos cloth, each about 0.045" thick. The width of the lower strip must be such as to cover the space between the clip on the coil end and the end of the fiber strip between the layers in the slot portion. Each successive strip is narrower in order to provide a solid bed for the end bands. The strips between end windings are important not only with respect to banding, but also for the insulation between upper and lower coil ends which cross one another. For

Class B windings a canvas base bakelite material is to be used between upper and lower layers in the slot portion and a treated glass or asbestos cloth between upper and lower layers in the end windings. For Class H insulation the material to be used between upper and lower layers in the slot portion must be melamine. The separators between upper and lower layers in the end windings consist of two or more strips of silicone glass or silicone-treated asbestos cloth.

Clip Insulation. In order to connect the coils in series, connections between the upper and lower layers have to be made. When the copper strap is heavy, spacers of tinned copper are driven between the layers of the leads after the copper clips have been slipped over them. When the copper strap is light, the clips are squeezed together in the middle in the form of a figure 8,forcing the upper and lower straps away from the middle of the clip. The clips are soldered. All clips must be tightened with wooden wedges before soldering in order to get a tight joint between leads. The wooden wedges can be removed after the excess of soldering metal either has been machined off or wiped off in the process of soldering. The insulation of the clip consists of two or more caps or bags of 0.017" muslin, depending upon the voltage between the slip rings and space between adjoining clips. The clip insulation has to be applied before banding. For Class H windings the clips must be soldered with a high-temperature solder or brazed. The insulation of the clips will consist of caps or bags of silicone-treated glass cloth. In some cases silicone glass mica tape and silicone glass tape can also be used for clip insulation.

Support Insulation. The end windings rest on supports which must be insulated. Treated fuller-board held in position by cotton tape is used for Class A windings. In some applications bias-cut varnished tape and cotton tape is also used. For Class B windings, treated asbestos cloth held in place with glass tape or asbestos tape is used. For Class H windings the insulation would consist of silicone glass cloth or silicone mica-glass held in place by silicone glass tape.

Mechanical Clearances. The mechanical clearances must be the same as for the lap windings (see Art. 2-6). The creepage distance must also be sufficient with respect to the supports.

Wedges. After inserting the conductors, the slot cells or troughs are trimmed, leaving enough length for an overlap on the top of the coils. A fiber strip is then put above the cell which serves as a slide for the wedges. The wedges consist usually of two or more pieces which are driven in from each end of the rotor. The wedge material is fiber or canvas base bakelite. The wedges for Class B windings are made from canvas base bakelite or glass base bakelite, whereas the wedges for Class H insulation are made from melamine. The dimensions of the wedge depend upon the weight of the copper in the slot, i.e., upon the slot dimensions. Figs. 2-21a, b, and c show the usual wedge shapes. The corresponding Table 2-10 gives the wedge dimensions (in inches) for the different slot widths. The wedge should be longer than the slot by 1/2" to 3/4" depending upon the thickness of the wedge.

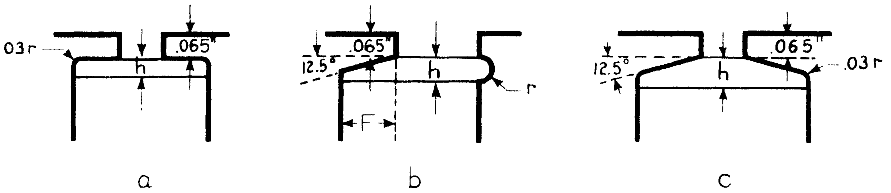


Fig. 2-21. Slot wedge shapes

Banding of the End Windings. Special attention must be paid to a proper banding of the end windings since they are subject to centrifugal forces. Usually steel wire is used with a diameter of 0.029" for rotor diameters up to 10"; 0.045" for rotor diameters 10" to 15"; 0.064" for rotor diameters 15" to 25"; and 0.081" for rotor diameters greater than 25". The 0.064" wire is often applied instead of the 0.029" or 0.045" wires. During the banding process, the wire should have a tension which is about 70% of the maximum permissible wire tension, in order to take care of overspeeds. The maximum permissible wire tension (in pounds) is: 80 for 0.029" wire; 200 for 0.045" wire; 250 for 0.064" wire when applied to wire or ribbon coils, and 400 when applied to strap coils; 550 for 0.081" wire, which is used only for strap coils.

The number of wires in the band is governed by the stress in the band. For the latter, the following formula can be used:

$$S = 2.25\ WD \times \left(\frac{\text{rpm}}{1000}\right)^2 \text{ pounds} \qquad (2\text{-}4)$$

where S is the total stress in the band, W is the total weight (in pounds) of the end windings, including insulation and banding, D the rotor diameter (in inches), and rpm the rated speed. The band should cover about 60% of the coil ends.

Two layers of 0.010" mica and one of .035" asbestos are usually used as insulation between end windings and band wire. The insulation must extend on each side 3/8" to 1/2" beyond the last turn of wire.

Tinned steel clips, 3/8" to 1/2" wide and 0.012" to 0.022" thick, must be placed under the bands. The length of the clips must be such as to permit a turnover on top of about half an inch at each end. The clips are spaced about 4 slots apart. At the start and stop of the band, 3 clips, close to each other, are usually used.

C. SQUIRREL-CAGE WINDINGS

2-8. Different kinds of Squirrel-cage Windings. Some slot shapes for squirrel-cage rotors are shown in Fig. 2-22. The rotor bars are not insulated; they are connected on each side by a ring. In rotors with a diameter up to about 12", the bars and rings are made, by the larger manufacturers, of die cast aluminum for which different compositions are available (Fig. 2-23). Otherwise, the bars are made of round (Fig. 2-24) or rectangular (Figs. 2-25 and 2-26) copper and sometimes also of brass. The rings are made of either copper or brass or other material of higher resistivity.

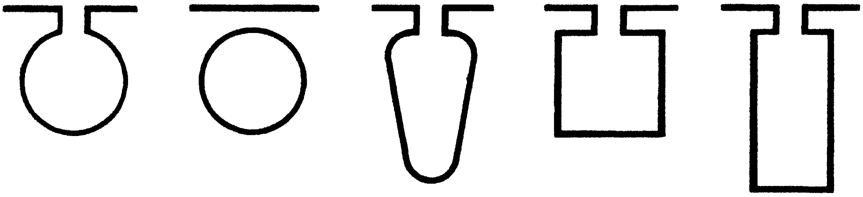


Fig. 2-22. Slot shapes for squirrel-cage rotors

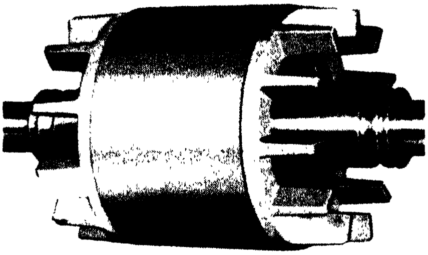


Fig. 2-23. Complete rotor with die-cast aluminum bars, end rings, and ventilating fans

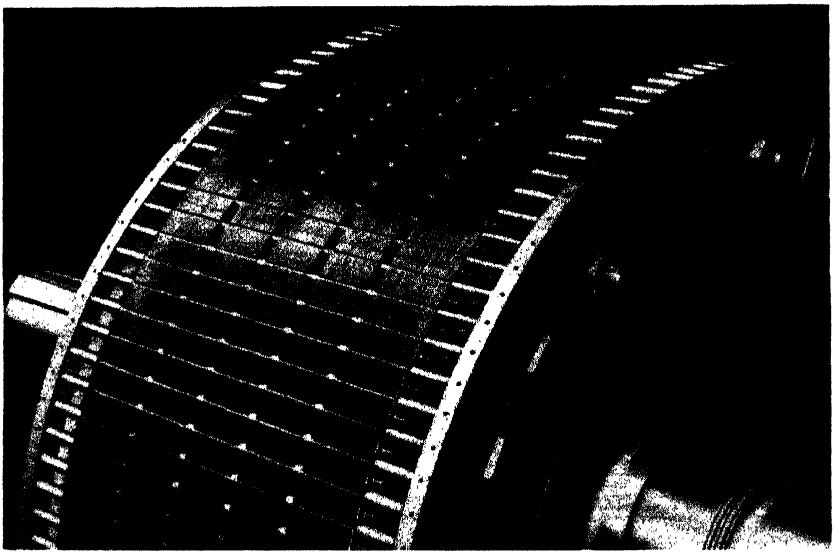


Fig. 2-24. Squirrel-cage rotor with round bars

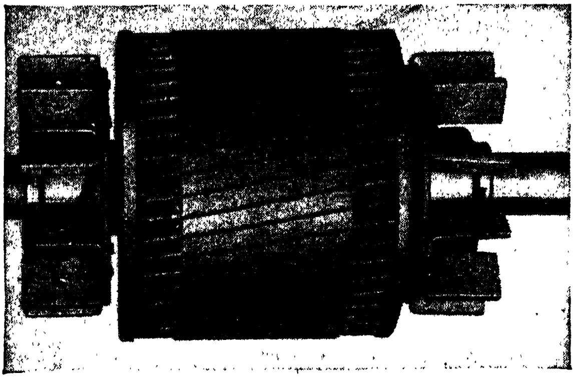


Fig. 2-25. Squirrel-cage rotor with rectangular bars

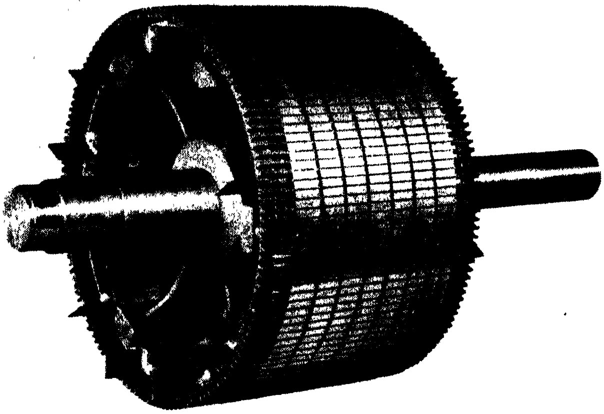


Fig. 2-26. Complete squirrel-cage rotor for a large induction motor

For certain purposes, 2 cages are arranged in the rotor. Some slot shapes for double-cage rotors are shown in Fig. 2-27. There may be 2 rings on each side, one for each cage (Fig. 2-28),

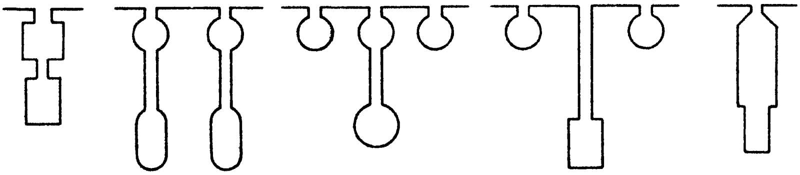


Fig. 2-27. Slot shapes for double-cage rotors.

or only one ring on each side, which is then common for both cages.

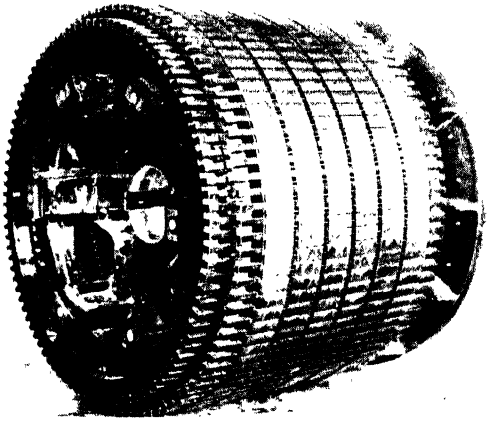


Fig. 2-28. Complete double-cage rotor

Bolts, solder, bolts and solder, brazing, and welding are used to connect the bars to the end rings. The last 2 are most often used in present-day practice.

TABLE 2-1 - STANDARD CLASSIFICATION OF INSULATING MATERIALS AND TEMPERATURE LIMITS

Class	Material Classification	Limiting Temperatures, ° C for Industrial Apparatus		
		Thermometer	Embedded Detector	Hot Spot
O - Untreated organics	Untreated fabrics of cotton, silk, linen. Untreated paper, fiber, wood, etc.	75	85	90
A - Treated or impregnated organics	Cotton, silk, linen, and similar organic materials when impregnated in oil, varnish, wax, or compounds. Oil, varnish, bakelite, and organic fillers. Enamel as applied to wires.	90	100	105
B - Treated or impregnated inorganics	Asbestos, fiberglas, mica tape, oxide films, inorganic fillers, asbestos boards. (A limited amount of organic materials may be used for binding or structural purposes.)	110	120	130
H - Treated or impregnated inorganics	Mica, asbestos, fiberglas and similar inorganic materials in built up form with binding substances composed of silicone compounds, or materials with equivalent properties; silicone compounds in rubbery and resinous forms, or material with equivalent properties in minute proportions. Class A material may be had only where essential for structural purposes during manufacture.	-	-	180

TABLE 2-2 - MATERIALS FOR CONDUCTOR INSULATION

CLASS O	CLASS A	CLASS B	CLASS H*
Single cotton	Single cotton	Single glass	Single glass
Double cotton	Double cotton	Double glass	Double glass
Cotton tape	Triple cotton	Triple glass	Triple glass
Cotton sleeving	Cotton tape	Glass tape	Glass tape
Paper	Enamel	Glass sleeving	Glass sleeving
	Single-cotton enamel	Asbestos	Asbestos
	Double-cotton enamel	Asbestos tape	Asbestos tape
	Cotton sleeving	Mica tape	Mica tape
	Paper		
	Paper and enamel		
	Cellophane		
	Cellophane and enamel		

* All materials must be bonded with silicone varnishes.

TABLE 2-3 - MATERIALS FOR GROUND INSULATION

CLASS O	CLASS A	CLASS B	CLASS H
Fishpaper Rope paper Fuller-board Cotton tape Wood Fiber	Fishpaper and Varnished cloth Varnished cloth Bias-cut varnished cloth tape Paper base bakelite Cloth base bakelite Wood Fiber	Fishpaper and mica Rope paper and mica Asbestos paper and mica Glass cloth and mica Cellophane and mica Mica tape Asbestos base bakelite Glass base bakelite	Silicone glass cloth and mica Silicone glass mica tape Melamine Glass base silicone

TABLE 2-4 - NORMAL GROUND INSULATION FOR CLASS A, B AND H COILS

Voltage Range	Class A		Class B		Class H ***	
	Material	Turns of Wrapper or Mica Wall Thickness	Material	Turns of Wrapper or Mica Wall Thickness	Material	Turns of Wrapper or Mica Wall Thickness
to 600	.010" VC .010" FP & M	1 1/4 to 2 1/4	.010" FP & M	1 1/4 to 2 1/4	.010" SGC	1 1/4 to 2 1/4
600 to 1200	.010" VC .010" FP & M	3 1/4	.010" FP & M .006" MT	2 1/4 to 3 1/4 .024"	.010" SGC .004" SGMT	2 1/4 to 3 1/4 .024"
1200 to 2500	.012" VC .012" FP & M	3 1/4	.012" FP & M .006" MT	3 1/4 .036"	.010" SGC .004" SGMT	3 1/4 .036"
2500 to 3500	.012" FP & M .012" KP & M	3 1/4	.012" FP & M .008" MT	3 1/4 .048"	. . . .	. . . .
3500 to 4500	.012" KP & M	4 1/4	.012"KP & M .008" MT	4 1/4 .064"	. . . .	. . . .
4500 to 6600*	.015" KP & M	4 1/4	.015" KP & M .008" MT	4 1/4 .096"	. . . .	. . . .
6600 to 11,000**	. . . .	. . . .	.008" MT	.145"	. . . .	. . . .
11,000 to 13,200**	. . . .	. . . .	.008" MT	.190"	. . . .	. . . .

VC = Varnished cloth
FP & M = Fishpaper and mica
KP & M = Kraft paper and mica

MT = Mica tape
SGC = Silicone glass cloth
SGMT = Silicone glass mica tape

* Coils with wrappers are vacuum-pressure impregnated before ground insulation is applied; coils with mica tape are vacuum-pressure impregnated after ground insulation is applied.

** Coils are vacuum-pressure impregnated after a partial application of ground insulation and again after the final application of the ground insulation.

*** Coils for voltages greater than 2500 volts have not been manufactured and data available are limited.

TABLE 2-5 - MATERIALS FOR END WINDING INSULATION

CLASS O	CLASS A	CLASS B	CLASS B
Cotton tape	Cotton tape	Glass tape	Silicone glass tape
Cotton sleeving	Bias-cut varnished tape	Varnished glass cloth	Silicone glass cloth
	Varnished cloth	Asbestos tape	Silicone glass mica tape
		Treated asbestos cloth	
		Mica tape	

TABLE 2-6 - END WINDING INSULATION

VOLTAGE	PHASE COIL				PLAIN COIL				FINISH TAPE			Varnish Treatment
RANGE	CLASS A	CLASS B	CLASS H***	No. Layers or Mica Wall Thickness	CLASS A	CLASS B	CLASS H***	No. Layers or Mica Wall Thickness	CLASS A	CLASS B	CLASS H***	
to 600	.007" CT	.007" GT	.007" SGT	1	. . . . .	. . . .	. . . . .	0	.007" CT	.007" GT	.007" SGT	2
600 to 1200	.010" BTC	.006" MT	.004" SGMT	1	.007" CT	.006" GT	.007" SGT	1	.007" CT	.007" GT	.007" SGT	2
1200 to 2500	.010" BTC	.006" MT	.004" SGMT	2	.010" BTC	.006" MT	.004" SGMT	1	.007" CT	.007" GT	.007" SGT	2
2500 to 3500	.010" BTC	.008" MT	. . . . .	3	.010" BTC	.008" MT	. . . . .	2	.007" CT	.007" GT	. . . . .	2
3500 to 4500	.010" BTC	.008" MT	. . . . .	4	.010" BTC	.008" MT	. . . . .	3	.007" CT	.007" GT	. . . . .	3
4500 to 6600*	.010" BTC	.008" MT	. . . . .	6	.010" BTC	.008" MT	. . . . .	5	.007" CT	.007" GT	. . . . .	3
6600 to 11000**	. . . .	.008" MT	. . . . .	.145"	. . . . .	.008" MT	. . . . .	.145"	. . . .	.010" GT	. . . . .	. .
11000 to 13200**	. . . .	.008" MT	. . . . .	.190"	. . . . .	.008" MT	. . . . .	.190"	. . . .	.010" GT	. . . . .	. .

CT = Cotton tape
GT = Glass tape
MT = Mica tape

BTC = Bias cut varnished cotton tape
SGT = Silicone glass tape
SGMT = Silicone glass mica tape

* Only Class A coils receive vacuum-pressure impregnation before application of end-winding insulation.

** Coils are vacuum-pressure impregnated after a partial application of end-winding insulation and again after the final application of the end-winding insulation.

*** Coils for voltages greater than 2500 volts have not been manufactured and data available are limited.

TABLE 2-7 - MECHANICAL CLEARANCES
(all dimensions in inches)

Voltage Range	Top Cell Extension	Bottom Cell Extension	Distance to Retaining Ring or Clamp	Distance from Conn. to End Brackets	Distance between End Windings
	A	B	C	D	E
Semi-open slots*	1/4	1/4	1/4	1/4	-
Semi-open slots**	1/2 to 5/8	3/8	5/16	1/4	1/16 to 3/32
Open slots					
Up to 600	1/2 to 3/4	3/8 to 5/8	3/8	1/4	3/32
600 - 1200	5/8 to 7/8	9/16 to 3/4	1/2	3/8	3/32
1200 - 2500	7/8 to 1 1/8	3/4 to 1	5/8	1/2	1/8
2500 - 3500	1 1/8 to 1 3/8	1 to 1 1/8	3/4	5/8	5/32
3500 - 4500	1 3/8 to 1 3/4	1 1/8 to 1 1/2	1	7/8	3/16
4500 - 6600	1 3/4 to 2 1/2	1 1/2 to 1 3/4	1 1/4	1 1/4	3/16
6600 - 11000	2 1/2 to 3	1 3/4 to 2 1/2	1 1/2	1 3/4	1/4 to 5/16
11000 - 13200	3 to 4	2 1/2 to 3 1/4	1 3/4	2	5/16 to 11/32

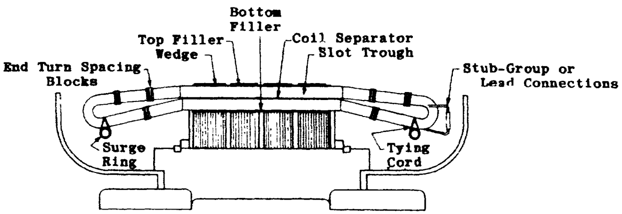
* For motors up to 7 1/2 HP and 240 volts.

** For motors greater than 7 1/2 HP and up to 600 volts.

TABLE 2-8 - NORMAL COIL INSULATION FOR CLASS A ROTOR WAVE WINDINGS

Voltage Range	Cell Insulation		End-winding Insulation			Outside Finishing Tape
	Material and Thicknesses	No. Turns	Material and Thicknesses	No. of half lap layers		
				Plain Coils	Phase Coils	
Up to 600	.012" Fishpaper and mica	1½	.012" Bias-cut varnished cloth tape	0	1	.007" cotton tape
600 to 1200	.012" Fishpaper and mica	2½	.012" Bias-cut varnished cloth tape	1	2	.007" cotton tape
1200 to 2400	.012" Fishpaper and mica	3½	.012" Bias-cut varnished cloth tape	2	3	.007" cotton tape

TABLE 2-9 - GUIDE FOR STATOR REWINDING MATERIALS



TYPE	LOCATION	SEMI-CLOSED SLOT STATORS			OPEN SLOT STATORS		
		For Class A Coils	For Class B Mica-Glass Coils	For Class H Silicone Mica-Glass Coils	For Class A Coils	For Class B Mica-Glass Coils	For Class H Silicone Mica-Glass Coils
SLOT	Slot trough	Fish paper and varnished cloth	Mica-glass	Silicone mica-glass	Fish paper	None -- if necessary, use uncut mica or stiff varn. glass	None -- if necessary to tighten coil in slot use uncut mica
	Bottom filler	. . . .	. . . .	. . . .	Fishpaper Pressboard Fiber	Asbestos base bakelite Glass base bakelite Moulding mica	Glass base silicone Glass base melamine
	Separator	Fishpaper Pressboard Fiber	Oiled asbestos	Silicone varnished glass	Same as bottom filler above	Same as bottom filler above	Same as bottom filler above
	Wedge and top filler	Kiln dried maple Fishpaper Pressboard Canvas base bakelite Fiber	Asbestos base bakelite Glass base bakelite	Glass base silicone Glass base melamine	Fiber Kiln dried maple Canvas base bakelite	Asbestos base bakelite Glass base bakelite	Glass base silicone Glass base malamine
CORE	Surge rings	. . . .	. . . .	. . . .	Varnished cloth bias cut tape Cotton tape	Mica tape Treated glass tape	Silicone mica-glass tape Silicone glas tape

TABLE 2-9 - Concluded

TYPE		LOCATION	SEMI-CLOSED SLOT STATORS			OPEN SLOT STATORS		
			For Class A Coils	For Class B Mica-Glass Coils	For Class H Silicone Mica-Glass Coils	For Class A Coils	For Class B Mica-Glass Coils	For Class H Silicone Mica-Glass Coils
END		Spacing blocks	. . . .	. . . .	. . . .	Kiln dried maple Canvas base bakelite Fiber Pressboard	Asbestos base bakelite Glass base bakelite	Glass base silicone Glass base melamine
		Between phase coils	Varnished cloth	Mica glass	Silicone mica-glass	. . . .	. . . .	. . . .
		Tying cords	Flax cord	Treated glass cord Flax cord	Silicone glass cord	Flax cord	Treated glass cord Flax cord	Silicone glass cord
COIL CONNECTIONS		Stub, group, and lead connections	Plastic tubing Varnished cotton tubing Cotton tape	Varnished glass tubing Mica tape Treated glass tape	Silicone glass tubing Silicone mica-glass tape Silicone glass tape	Plastic tubing Varnished cotton tubing Varnished cloth bias cut tape Cotton tape	Mica tape Treated glass tape	Silicone mica-glass tape Silicone glass tape
LEADS		For external connections	Cotton covered cable Rubber insulated braided cable	Glass braid covered cable Asbestos varnished cloth cable	Flex. copper strands slipped through silicone tubing Silicone rubber & glass cable	Rubber insulated braided cable	Glass braid covered cable Asbestos varn. cloth cable	Flex. copper strands slipped through silicone tubing Silicone rubber & glass cable
SOLDERING SUPPLIES		Solder	50 - 50 solder Copper fusion	100% Tin 95% tin 5% antimony Hi-temp. alloy Copper fusion	Silver solder Hi-temp. alloy Copper fusion	50 - 50 solder	100% tin 95% tin 5% antimony Hi-temp. alloy Silver solder	Silver Solder Hi-temp. alloy
		Flux	Rosin solution	Rosin solution Borax or silver solder flux	Rosin solution Borax or silver solder flux	Rosin solution	Rosin solution Borax or silver solder flux	Rosin solution Borax or silver solder flux
VARNISH	Dipping	Winding	Long life synthetic baking varnish	Long life synthetic baking varnish	Silicone	Long life synthetic baking varnish	Long life synthetic baking varnish	Silicone
	Finishing	Winding	Oil proof air dry varnish	Oil proof air dry varnish	Silicone	Oil proof air dry varnish	Oil proof air dry varnish	Silicone
		Frame	Enamel	Enamel	Heat resistant enamel	Enamel	Enamel	Heat resistant enamel

TABLE 2-10 - WEDGE DIMENSIONS FOR WOUND ROTORS

Figure No.	Slot Width	h	F	r
Fig. 2-21a	Up to 0.5	1/16	-	-
Fig. 2-21b	Up to 0.44	1/16	5/32	0.04
	> 0.44 to 0.50	3/32	7/32	0.048
	> 0.50 to 0.75	1/8	9/32	0.063
	Above 0.75	5/32	7/16	0.08
Fig. 2-21c	> 0.03 to 0.05	1/16	-	-
	> 0.05 to 5/8	3/32	-	-
	> 5/8 to 7/8	1/8	-	-
	Above 7/8	5/32	-	-

All dimensions are in inches.

CHAPTER 3

INTEGRAL-SLOT LAP WINDINGS (LAP WINDINGS WITH EQUAL COIL GROUPING)

A. CONNECTION DIAGRAMS AND CONNECTION TABLES

3-1. Windings Treated in This Chapter. In this chapter, the polyphase lap windings will be considered for which

$$\frac{\text{Total No. of Slots}}{\text{No. of poles x No. of phases}} = \text{Integer}$$

i.e., the windings in which the number of slots per pole per phase (see Chapter 1) is an integer and, therefore, all pole-phase groups have the same number of single coils. For example, a stator with 54 slots for a 6-pole, 3-phase motor has $\frac{54}{6 \times 3} = 3$ slots per pole per phase (spp = 3), and each pole-phase group consists of 3 single coils; a stator with 72 slots for a 4 pole, 3 phase motor has $\frac{72}{4 \times 3} = 6$ slots per pole per phase, and consequently each pole-phase group has 6 single coils. These are lap windings with equal coil grouping in contrast to the lap windings with unequal coil grouping described in Chapter 4.

3-2. Presentation, Numbering, and Designation of Pole-phase Groups. In the following Connection Diagrams, a pole-phase group will be represented by a single line. Therefore, a winding laid out for a certain number of slots per pole per phase is applicable to any number of slots per pole per phase, provided the number of poles and number of phases remain unchanged.

In all Connection Diagrams, the consecutive pole-phase groups of the winding will be designated by the clockwise numbering 1, 2, 3, 4, and so forth, and the different phases to which these groups belong will be designated by the letters A and B in a 2-phase winding, and by the letters A, C, and B in a 3-phase winding. The reason for the choice of the sequence A, C, B, and not A, B, C, for 3-phase windings is explained in Art.3-3. Furthermore, different kinds of lines are used to denote the different phases. In 2-phase windings, a heavy solid line is used for phase A, and a light dotted line for phase B. For 3-phase windings, a heavy solid line is used for phase A, a light dotted line for phase B, and a light solid line for phase C.

3-3. Connection Diagrams and Connection Tables and How to Use Them.

(Figs. 3-10 to 3-122 are at end of chapter). As has been explained in Art. 1-6, each phase has as many pole-phase groups as there are poles. For example, in a 2-pole machine, each phase has 2 pole-phase groups (see Fig. 3-37); in a 4-pole machine, each phase has 4 pole-phase groups (see Fig. 3-43), and so forth. The pole-phase groups of each phase can be connected all in series (see Fig. 3-65), or all in parallel (see Fig. 3-68), or parts of the pole-phase groups can be connected in series and these series-connected parts then connected in parallel (see Fig. 3-67).

The maximum possible number of parallel circuits for integral slot windings is equal to the number of pole-phase groups in the phase, i.e., to the number of poles. If a smaller number of parallel paths is desirable, the number of poles must be divisible by this smaller number. For example, in a 12-pole machine, a maximum of 12 parallel circuits are possible, but also 6, 4, 3, and 2 parallel circuits can be made because 12 is divisible by each of these numbers. When, for example, 4 parallel circuits are desired, the consecutive 12 pole-phase groups of each phase are series-connected in groups of 3, and the 4 series-connected groups are connected in parallel (see Fig. 3-94).

Two consecutive pole-phase groups of the same phase lie under poles of different polarity, and the current flows in them in different directions; 2 alternate pole-phase groups of the same phase lie under poles of the same polarity, and the current flows in them in the same direction. The current direction of the individual pole-phase groups is indicated by arrows. Consider, for example, Fig. 3-43. Corresponding to the given rule, pole-phase group 4 is provided with an arrow which is opposite to that of pole-phase group 1, while pole-phase group 7 has an arrow of the same direction as that of pole-phase group 1. It follows from the same rule that for the series connection of 2 consecutive pole-phase groups of the same phase, the end of one group must be connected with the end of the other group (see Fig. 3-43) and that, for the series connection of 2 alternate pole-phase groups of the same phase, the end of one group must be connected with the beginning of the other group (see Fig. 3-31)

The first kind of series connection of pole-phase groups is called short-jumper or top-to-top or bottom-to-bottom connection; the second kind is called long-jumper or top-to-bottom connection. The latter kind of connection is used mainly in smaller machines (see Art. 3-5) All the Connection Diagrams given, except Figs. 3-31 to 3-36, are for the short-jumper connection. All the Connection Tables also are for the short-jumper connection.

In a 3-phase, integral-slot winding, the beginnings of phases lie 2/3 of a pole pitch or 2/3 of a pole pitch plus any even number of full pole pitches apart (see Art. 1-9). Since a pole-phase group occupies, in a 3-phase winding, 1/3 of a pole pitch (the single exception of this rule is treated in Chapter 9), the beginnings of the phases can be placed 2 pole-phase groups apart, i.e., if phase A starts at the beginning of pole-phase group 1, phase B may be started at the beginning of pole-phase group 3, and phase C at the beginning of pole-phase group 5. Therefore, if pole-phase group 1 is assigned to phase A, pole-phase group 3 must be assigned to phase B. Pole-phase group 2 which lies between phases A and B must then belong to phase C. This explains the sequence A, C, B, in the connection diagrams of the 3-phase windings.

Table 3-1 enumerates the standard 2-phase Connection Diagrams and the corresponding Connection Tables (3-6 to 3-9) which are worked out in this chapter. Table 3-2 enumerates the standard 3-phase Connection Diagrams and Tables with long-jumper or top-to-bottom group connectors worked out in this chapter. Since windings using the long-jumper connectors are not the most commonly used, only the Connection Diagrams for 4 poles are worked out, but the method for laying out such windings is described in detail in Art. 3-10. Table 3-3 enumerates the standard 3-phase Connection Diagrams and Tables with short-jumper or top-to-top group connectors, worked out in this chapter.

Table 3-4 is a Master Table for 2-phase windings showing for different numbers of poles (up to 24) and different numbers of slots (up to 144) the corresponding values of spp and the number of pole-phase groups. Table 3-5 is the corresponding Master Table for 3-phase windings; however, it is extended to 52 poles and 540 slots. The purpose of these Master Tables is to enable the winder to determine at a glance the proper number of pole-phase groups, and the proper number of slots per pole per phase for any given combination of slots and poles. For the integral-slot windings, the spp is denoted in heavy print. For those windings with a fractional number of slots per pole per phase which are balanced, the spp is given in normal print (these windings are discussed in Chapters, 4, 6, and 7), whereas, for those windings with a fractional number of slots per pole per phase which are unbalanced (discussed in Chapters 5 and 8), the spp is denoted in italics*. The Tables, then, in addition to giving the data on spp, also point out whether the winding is balanced or unbalanced. They also give a clue to the proper grouping for the particular winding, but this part of the table will be discussed later.

The Connection Diagrams (see pp. 89 - 191) are complete and show how the pole-phase groups are to be connected for series as well as for parallel connections. For 3-phase windings, diagrams are given for star as well as delta connections. Diagrams are given also for the dual-voltage connections. Small motors are usually designed so that they may be used readily for dual voltages, for example, 220 and 440 volts, or 110 and 220 volts.

The Connection Tables 3-6 to 3-9 for 2-phase windings, and 3-10 to 3-24 for 3-phase windings, have been worked out only for the short-jumper connection as mentioned above. The long-jumper connection can be used for all integral-slot windings, but it cannot be used for certain fractional-slot windings (see Chapter 4) and, therefore, must be used with caution. Although the Connection Diagrams and Tables shown consider only a limited number of poles and slots, detailed information is given in Arts. 3-4 to 3-15 which enables the winder to lay out a winding for any number of poles and any desired connection. The use of the diagrams and tables for integral-slot lap windings will be explained by a few examples.

Consider first a 2-phase, 48-slot, 8-pole winding, connected series. The Master Table 3-4 for 2-phase windings shows that for 8 poles and 48 slots there are 16 pole-phase groups, and spp = 3, i.e., each pole-phase group consists of 3 single coils. Table 3-1 shows that for 8 poles and series connection the proper Connection Diagram is Fig. 3-24. If, for the same example, a 2-parallel connection is desired, Table 3-1 shows that Connection Diagram Fig. 3-25 is to be used.

Consider now a 3-phase, 168-slot, 14-pole winding connected series star. The Master Table 3-5 shows that for 168 slots and 14 poles there are 42 pole-phase groups, and spp = 4. Table 3-3 shows that for a series star connection, the proper Connection Diagram is Fig. 3-111. If, on the other hand, it is desired to connect this winding series delta, then, from the same table, Connection Diagram Fig. 3-117 is to be used. Other Connection Diagrams are indicated also. If the winding is to be connected without the use of Connection Diagrams, Table 3-3 indicates that Connection Table 3-16 can be used. In Table 3-16 the method is given for connecting the pole-phase groups of each phase for series, 2-parallel, 7-parallel and 14-parallel circuits. "S1" means start of group 1, "S4" means start of group 4, "F16" means finish of group 16, etc. The arrow indicates the group connector.

For the series connection of phase A, the line lead T_1 connects to the start of group 1 (S1). The end of phase A is T_4 which connects to the start of group 40 (S40). Similarly, for phase B, line lead T_2 connects to S3, and T_5 connects to S42; for phase C, line lead T_3 connects to S5, and T_6 connects to S2. Now for the series star, T_4, T_5, T_6 connect together, and T_1, T_2, T_3 are connected to line leads;for delta connection, T_4 connects with T_2, T_5 with T_3, and T_6 with T_1. The line leads are then connected to the junction of T_6-T_1, T_4-T_2, and T_5-T_3.

The Table also indicates how to change from a series connection to a 2-parallel connection. It can be seen that if, in phase A,the jumper connection between F19 and F22 is broken, and the end F22 is connected to S1, and the end F19 is connected to S40, a parallel connection of the phase is accomplished. The phases B and C can similarly be connected into 2 parallel circuits by following the Table. It is apparent from this that windings can be readily connected without the use of Connection Diagrams, and also, that it is a simple matter to change from a series to 2 parallel, or other combination, by using the Connection Tables. For this reason, the Tables have been worked out to 30 poles for 3-phase windings.

B. LAYOUT OF 2-PHASE WINDINGS

3-4. Layout of 2-Phase Windings. The layout and checking of a 2-phase winding can be best shown by an example. As such, a 4-pole machine will be considered. First, the number of pole-phase groups is to be determined. This can be done with the aid of Eq. 1-4, which says that

No. of pole-phase groups = No. of poles x No. of phases

i.e., in the case of a 4-pole machine, the number of pole-phase groups is 4 x 2 = 8. These 8 groups are shown in Fig. 3-1a. They are numbered clockwise by the consecutive digits 1 to 8. The groups 1, 3, 5, and 7 belong to phase A and are indicated by heavy lines; the groups 2, 4, 6, and 8 belong to phase B and are indicated by dotted lines.

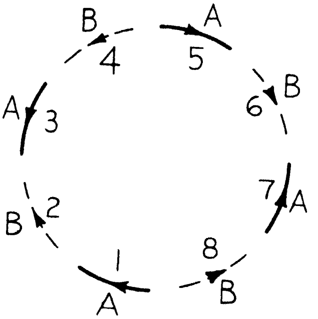


Fig. 3-1a. 2-phase, 4-pole winding. Arrangement of pole-phase groups.

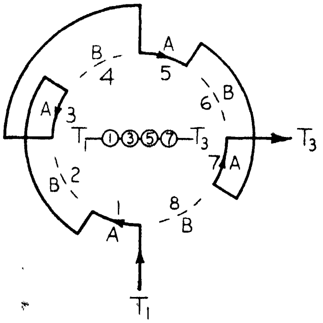


Fig. 3-1b. 2-phase, 4-pole winding, series connection of phase A.

Each pole-phase group has a start and a finish. Going around the circle in Fig. 3-1a clockwise, it will be assumed, as in the previously shown Connection Diagrams, that the beginning of each line representing a pole-phase group is the start of this pole-phase group, and the end of the line the finish of the pole-phase group. Then, since 2 consecutive pole-phase groups of the same phase lie under poles of different polarity, the series connection of these 2 consecutive pole-phase groups can be accomplished by connecting either their finishes or their starts together, while for the parallel connection of these same 2 consecutive pole-phase groups, the start of one pole-phase group must be connected with the finish of the other pole-phase group.

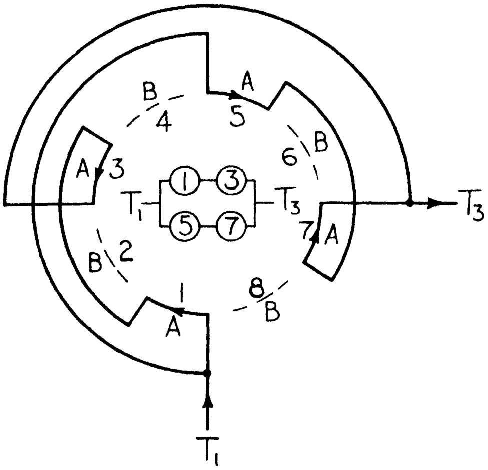


Fig. 3-1c. 2-phase, 4-pole winding, 2-parallel connection of phase A.

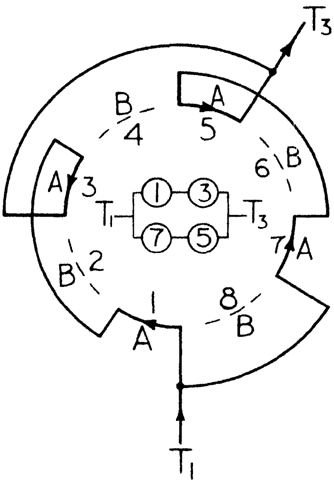


Fig. 3-1d. 2-phase, 4 pole winding, 2-parallel connection of phase A.

On the other hand, since 2 pole-phase groups of a phase separated by one group of the same phase lie under poles of the same polarity, for the series connection of such 2 groups, the finish of one group must be connected to the start of the other group; and for the parallel connection, the starts and also the finishes of both groups must be connected together, respectively.

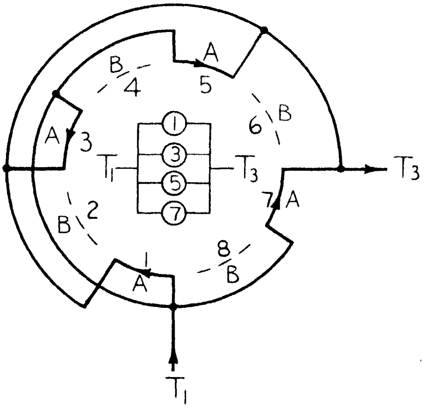


Fig. 3-1e. 2-phase, 4-pole winding, 4-parallel connection of phase A.

Fig. 3-1b shows the series connection of the 4 pole-phase groups of phase A. The finish of group 1 is connected to the finish of group 3, the start of group 3 is connected to the start of group 5, and the finish of group 5 is connected to the finish of group 7. The start of group 1 and the start of group 7 are the beginning (T_1) and end (T_3), i.e., the leads of phase A.

Fig. 3-1c shows the 2-parallel connection of the 4 pole-phase groups of phase A. The groups 1 and 3, and the groups 5 and 7, are connected in series respectively as in Fig. 3-1b, but here the start of group 5 is connected to the start of group 1, and the start of group 3 is connected to the start of group 7. The 2-parallel connection (Fig. 3-1c) is readily obtained from the series connection (Fig. 3-1b) by opening the jumper between start of group 3 and start of group 5, and connecting the start of group 3 to the lead T_3 and the start of group 5 to the lead T_1.

Fig. 3-1d shows another type of 2-parallel connection. The groups 1 and 3 are connected as in Fig. 3-1c; i.e., the finish of group 1 is connected to the finish of group 3. In the groups 5 and 7, the starts are connected together instead of the finishes and then the start of group 1 is connected with the finish of group 7 by a short jumper; and another short jumper connects the start of group 3 with the finish of group 5.

Comparing the 2 Connection Diagrams, Fig. 3-1c and Fig. 3-1d, the former requires less time and labor than the latter if the parallel connection is to be changed to a series connection. A further advantage of the Connection Diagram shown in Fig. 3-1c is explained in Art. 3-15.

Fig. 3-1e shows the 4-parallel connection of the 4 pole-phase groups of phase A. Here the start of group 1 is connected to the finish of group 3, to the start of group 5, and to the finish of group 7, and, further, the finish of group 1 is connected to the start of group 3, to the finish of group 5, and to the start of group 7. As stated previously, the maximum number of parallel circuits of the integral-slot, 2-layer lap winding is equal to the number of poles.

3-5. Short and Long Jumpers. Consider Fig. 3-1b for series connection. The consecutive groups of the same phase, for example, groups 1 and 3, groups 3 and 5, etc., lie under poles of different polarity, and the series connection is made in such a manner that 2 consecutive groups connected together belong to poles of different polarity. The series connection may be accomplished also in another way, namely, by connecting first in series all groups which lie under poles of the same polarity, and then by connecting together the 2 parts of the winding. This is shown in Fig. 3-2a. Here the finish of group 1 is connected by a long jumper to the start of group 5; the start of group 3 is connected by a long jumper to the finish of group 7; and the finish of group 5 is connected by a short jumper to the finish of group 3.

Fig. 3-2b shows the 2-parallel connection with long jumpers. Here the 2 series-connected groups 1 and 5, which lie under poles of the same polarity, are connected in parallel with the 2 series-connected groups 3 and 7, which lie under the poles of the other polarity.

In large machines, especially those with a large number of poles, the connection with short jumpers is preferred. The coil leads themselves are then made long enough to be used as jumpers, and no additional wire and additional soldered joints are necessary as with the long jumpers. Also, there are fewer crossovers than with the long jumpers. However, if the winding is connected 2-parallel, there can be effected a considerable savings in lead cable by using the long-jumper connection rather than the short-jumper connection. This scheme then brings all the beginnings and ends of the phases at one end of the winding rather than 180 mechanical degrees apart. In machines with a

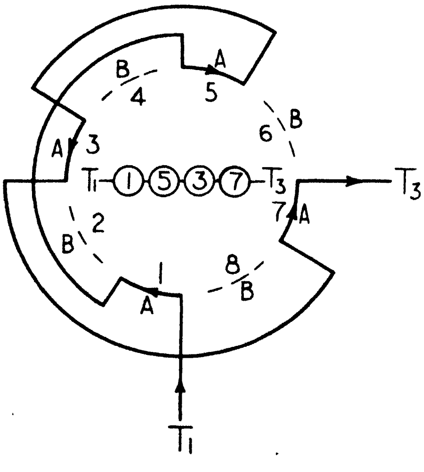


Fig. 3-2a. 2-phase, 4-pole winding, series connection with long jumpers.

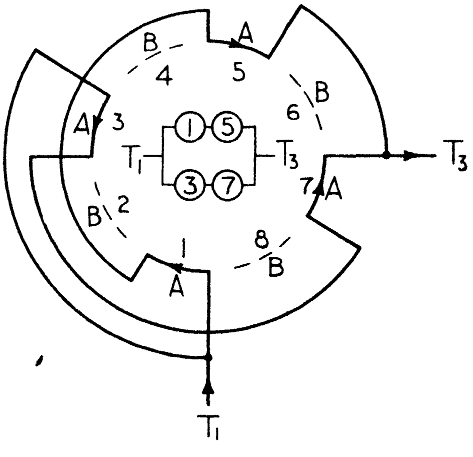


Fig. 3-2b. 2-phase, 4-pole winding, 2-parallel connection with long jumpers.

small number of poles and a series connection of all pole-phase groups in each phase, it does not make much difference whether the connection with short or long jumpers is used. In small machines, with a larger number of poles, the long-jumper connection is of some advantage, since it allows more working space than the short-jumper connection. As will be explained later (Art. 3-15) the connection with short jumpers has the advantage of compensating for magnetic side-pull to a much higher degree than the connection with long jumpers, when the winding has parallel paths.

3-6. Location of the Beginnings of the Phases.

In 2-phase windings, the beginnings of the phases lie one pole-phase group apart (see Art. 1-9), i.e., they are either the starts or the finishes of 2 consecutive pole-phase groups. Since there are 2 pole-phase groups per pole, the beginnings of the phases lie, in integral-slot windings, in slots which are half a pole pitch apart. Because of the symmetry of the winding, the ends of the phases also lie half a pole pitch apart. This rule is independent of the kind of connection, i.e., it holds for series as well as for any kind of parallel connection.

3-7. Checking of a 2-Phase Winding.

Since 2 consecutive groups of the same phase lie under poles of different polarity, the arrows on the lines representing the groups alternate their direction (Fig. 3-1a). Consider any of the Figs. 3-1 or 3-2, for example 3-1b. Following through the groups of phase A starting at terminal T_1, the connection of the groups must be such as to pass in the direction of all arrows. This is the case in Figs. 3-1b to 3-1d and 3-2. These figures show the connections of only phase A. If both phases are shown (see Fig. 3-1a and also, for example, Fig. 3-13), then the arrows in 2 adjacent groups have the same direction and, in the next 2 groups, the opposite direction. Thus, in order to check a 2-phase winding, start at the lead T_1 of phase A and draw an arrow assuming current to flow into this phase. Then trace the connections through all pole-phase groups of phase A from lead T_1 to lead T_3 and, while tracing through the groups, mark on each group by an arrow the direction in which the pencil traced through the particular group. Repeat the same with phase B starting at the lead T_2. The connection diagram is correct if 2 of the arrows point in one direction, the next 2 in the opposite direction, then the next 2 in the original direction, and so on. If this condition is not satisfied, the diagram is incorrect.

A similar method can be applied in checking a winding already placed in the slots. Each phase is checked separately by feeding it with direct current. However, it is important that the same d-c lead is connected to both motor leads T_1 and T_2, i.e., that current flows through both phases in the same direction. First apply current to the phase A and, with the aid of a compass held near the core at the centers of the pole-phase groups, mark the magnetic polarity of all groups (1, 3, 5, and so on) belonging to this phase. Start the marking with pole-phase group 1, which can be located by tracing the lead wire, and bear in mind that, if the north end of the needle points to the core, the polarity of that group is south (S). There should be as many pole-phase groups as there are poles, and the polarity should alternate N and S. Now the d-c leads are changed to phase B, and, starting with pole-phase group 2, the pole-phase groups of this phase are marked using a different-colored chalk or locating the markings at a different point, for example, the markings of phase A at one end of the core and the markings of phase B at the other end. Then, if the winding is correctly connected, 2 of the pole-phase groups should be marked N, the next 2 should be marked S, then the next 2 again N, and so on. The number of pairs will be equal to the number of poles.

The existence and direction of the driving force (i.e., of the rotating field) can be checked on 2-phase as well as 3-phase windings by a dummy rotor or a steel ball. This check, however, does not always guarantee that all single coils are connected correctly.

3-8. Dual-voltage Connections. As mentioned previously, small motors up to approximately 15 HP are usually designed by the manufacturers in such a manner that they may be readily used for two or more different voltages. For example, a winding may be laid out to have a series connection for 220 volts and a 2-parallel connection for 110 volts; or series connection for 440 volts and 4-parallel connection for 110 volts. The change from one voltage to the other is simplified when extra leads are brought out. If, for example, in Fig. 3-1b the starts of groups

3 and 5 are brought out as leads, then the connection Fig. 3-1c for 2 parallel circuits can be easily made, and the winding can be used for 2 voltages which have the ratio of 2 to 1. The number of leads per phase here is 4 instead of 2 for the single-voltage motor. With 8 leads per phase, the series connection Fig. 3-1b can be readily changed to 2 as well as to 4 parallel circuits (Figs. 3-1c and 3-1e).

C. LAYOUT OF 3-PHASE WINDINGS

3-9. Layout of 3-Phase Windings. The slots belonging to one pole of a 3-phase winding are divided in 3 parts corresponding to the number of phases, i.e., there are 3 pole-phase groups per pole, differing from the 2-phase winding which has only 2 pole-phase groups per pole. Two consecutive groups belonging to the same phase are 2 pole-phase groups apart.

The layout of the 3-phase winding will be studied on a 4-pole machine as was done for the 2-phase winding. The number of pole-phase groups is given by Eq. 1-4, namely,

No. of pole-phase groups = No. of poles x No. of phases

Thus, in the case of the 4-pole winding, the number of pole-phase groups is equal to 4 x 3 = 12. Fig. 3-3a shows the 12 groups. They are numbered clockwise as before. The groups 1,

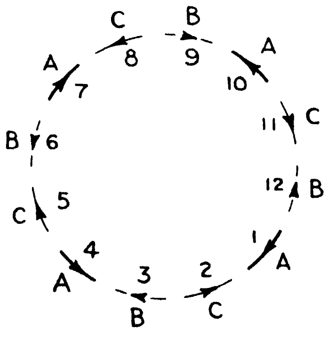


Fig. 3-3a. 3-phase, 4-pole winding. Arrangement of pole-phase groups

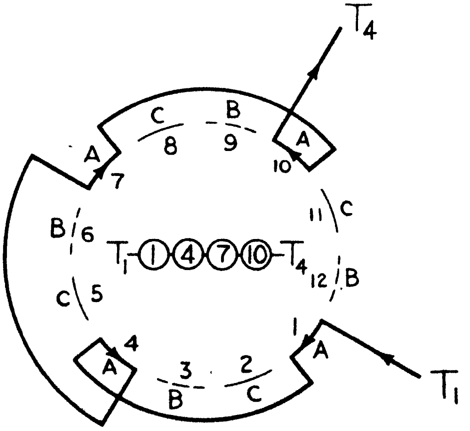


Fig. 3-3b. 3-phase, 4-pole winding, series connection of phase A.

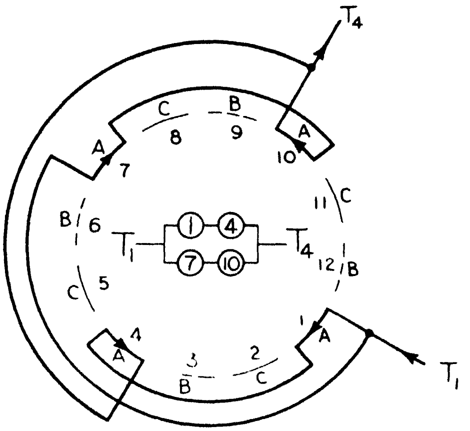


Fig. 3-3c. 3-phase, 4-pole winding, 2-parallel connection of phase A.

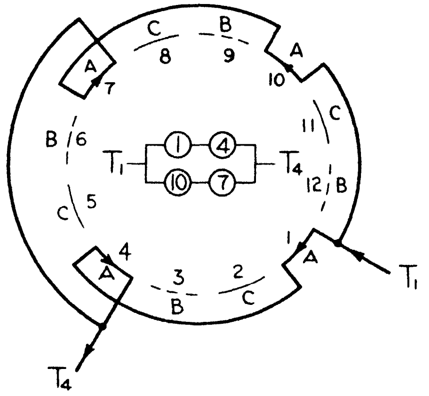


Fig. 3-3d. 3-phase, 4-pole winding, 2-parallel connection of phase A.

4, 7, and 10 belong to phase A; the groups 2, 5, 8, and 11 to phase C; and the groups 3, 6, 9, and 12 to phase B. The reason for assigning group 2 with its corresponding groups 5, 8, and 11 to phase C, and not to phase B, has been explained in Art. 3-3. In this, as in the following diagrams, the groups belonging to phase A are shown as heavy lines, the groups belonging to phase B as dotted lines, and the groups belonging to phase C as light solid lines. Since 2 consecutive pole-phase groups of the same phase lie under poles of different polarity, the arrows assigned to them must have different directions. Therefore, the arrow of group 4 (Fig. 3-3a) is opposite to the arrow of group 1, the arrow of group 7 opposite to that of group 4, and so on. For the explanation of the connections of the pole-phase groups, only phase A will be considered. The complete diagram is given in Fig. 3-5. Furthermore, it will be assumed again that, in clockwise direction, the be-

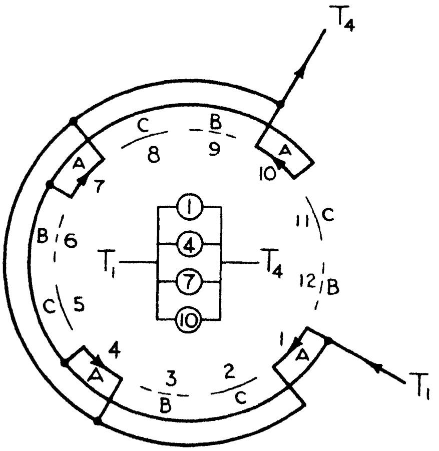


Fig. 3-3e. 3-phase, 4-pole winding, 4-parallel connection of phase A.

ginning of each line representing a pole-phase group is the start of this pole-phase group, and the end of the line, the finish of the pole-phase group. Then, as for the 2-phase winding, the series connection of 2 consecutive pole-phase groups of the same phase can be accomplished by connecting either their finishes or their starts together, while for the parallel connection of these same 2 consecutive pole-phase groups, the start of one pole-phase group must be connected with the finish of the other pole-phase group. On the other hand, since 2 pole-phase groups of the same phase which are one group (of this phase) apart lie under poles of the same polarity, for the series connection of such 2 groups, the finish of one group must be connected to the start of the other group, and for the parallel connection, the starts and also the finishes of both groups must be connected together, respectively.

Fig. 3-3b shows the series connection of the 4 pole-phase groups of phase A. Corresponding to the rule given above, the finish of group 1 is connected to the finish of group 4, the start of group 4 is connected to the start of group 7, and the finish of group 7 is connected to the finish of group 10. The start of group 1 and the start of group 10 are the beginning (T_1) and end (T_4), i.e., the leads of phase A.

Fig. 3-3c shows the 2-parallel connection of the 4 pole-phase groups of phase A. The groups 1 and 4 and the groups 7 and 10 are respectively connected in series as in Fig. 3-3b, but here the start of group 7 is connected to the start of group 1 and the start of group 4 is connected to the start of group 10. The 2-parallel connection (Fig. 3-3c) is readily obtained from the series connection (Fig. 3-3b) by opening the jumper between the start of group 4 and the start of group 7, and connecting the start of group 4 to the lead T_4, and the start of group 7 to the lead T_1.

Fig. 3-3d shows another type of 2-parallel connection. The groups 1 and 4 are connected as in Fig. 3-3c, i.e., the finish of group 1 is connected to the finish of group 4. In groups 7 and 10, the starts are connected together instead of the finishes, and then a short jumper connects the start of group 1 with the finish of group 10, and another short jumper connects the start of group 4 with the finish of group 7. The advantage of the 2-parallel connection of Fig. 3-3c over that of Fig. 3-3d is explained in Art. 3-15.

Fig. 3-3e shows the 4-parallel connection of the 4 pole-phase groups of phase A. Here the start of group 1 is connected to the finish of group 4, to the start of group 7, and to the finish of group 10, and, further, the finish of group 1 is connected to the start of group 4, to the finish of group 7, and to the start of group 10.

The maximum number of parallel circuits of the integral-slot, 2-layer lap windings is equal to the number of poles.

3-10. Short and Long Jumpers. In 3-phase windings as in 2-phase windings, the connections between the pole-phase groups may be made by either short or long jumpers.

Consider Fig. 3-3b for the series connection. Two consecutive groups of the same phase, for example, groups 1 and 4, 4 and 7, etc., lie under poles of different polarity, and the series connection is made in such a manner that 2 consecutive groups connected together belong to poles of different polarity. The series connection may be accomplished also in another way, namely, by connecting first, in series, all groups which lie under poles of the same polarity, and then by connecting together the 2 parts of the winding. This is shown in Fig. 3-4a. Here

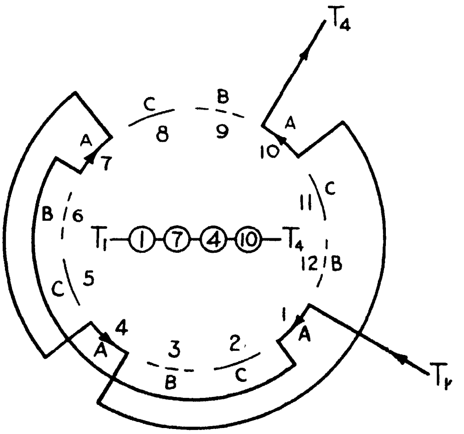


Fig. 3-4a. 3-phase, 4-pole winding, series connection with long jumpers.

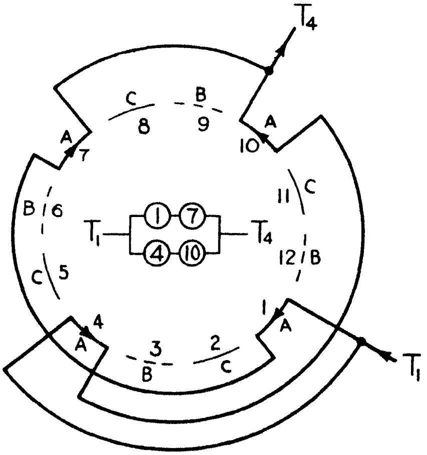


Fig. 3-4b. 3-phase, 4-pole winding, 2-parallel connection with long jumpers.

the finish of group 1 is connected by a long jumper to the start of group 7; the start of group 4 is connected by a long jumper to the finish of group 10;and the finish of group 7 is connected by a short jumper to the finish of group 4.

Fig. 3-4b shows the 2-parallel connection with long jumpers. Here the two groups 1 and 7 connected in series by a long jumper are connected in parallel with the two groups, 4 and 10, which are also connected in series by a long jumper. As in Fig. 3-4a, the groups 1 and 7 lie under poles of a polarity different from that of groups 4 and 10.

3-11. Location of the Beginnings of the Phases. The location of the beginnings of the phases is not as simple as for 2-phase windings. A 3-phase integral-slot winding consists of 3 parts displaced by 2/3 of a pole pitch, i.e., the beginnings of the 3 parts and, due to the symmetry of the winding, also their ends lie 2/3 of a pole pitch apart (see Art. 1-9 and Art. 3-3). Since a pole-phase group usually occupies, in a 3-phase winding, 1/3 of a pole pitch,it follows that the beginnings of the phases must be 2 pole-phase groups apart in order to satisfy the condition of being displaced with respect to each other by 2/3 of a pole pitch. Thus, in Fig. 3-3a, the starts or the finishes of the groups 1, 3, and 5, or the groups 11, 1 and 3, or of any other 3 groups which lie 2 pole-phase groups apart, can be taken as the beginning of the phases. However, with respect to the phase beginnings, it is permissible to substitute for any group one which lies 2 pole pitches (or a multiple of it) apart from it. For example, instead of using the starts or finishes of the groups 1, 3, and 5 as beginnings of the phases, the starts or finishes of the groups 7, 3, and 5, or the starts or finishes of the groups 1, 9, and 5 can be taken. In the first case, group 7 is substituted for group 1; in the second case group 9 is substituted for group 3. Group 7 lies 2 pole pitches apart from group 1, group 9 lies 2 pole pitches apart from group 3. Usually, the beginnings of the phases are outside leads and are located not far apart from each other.

3-12. Checking a 3-Phase Winding. Consider Fig. 3-5 which shows all 3 phases of the 4 pole windings treated before (see Figs. 3-3a to 3-4b). In order to check whether the connection diagram is correct or not, assume current to flow into each one of the 3 leads, T_1, T_2, and T_3. Trace each phase separately through all its groups, and mark on each group by an arrow the direction in which the pencil traced through the particular group. The connection diagram is correct, if no 2 adjacent arrows point in the same direction, i.e., if the direction alternates with each pole-phase group. This check is based upon the

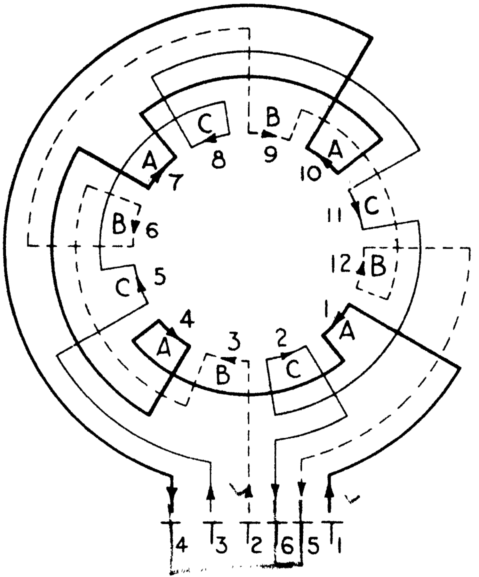


Fig. 3-5. 3-phase winding.
Checking the connections

fact that, if direct current flows into the 3 phases of a properly connected winding, a compass held against the consecutive pole-phase groups will show reversed polarity for the successive groups. It follows from this, that direct current can be used in order to check a winding already inserted into the slots. The procedure is different for a star- and a delta-connected winding (see Art. 3-13).

If the winding is star-connected, one d-c test lead is applied to the neutral point (or points if there are several parallel stars) and the other d-c test lead is applied to the leads T_1, T_2, and T_3 in succession (Fig. 3-6). With the d-c lead on T_1, use a compass in the manner explained in Art. 3-7, and mark the pole-phase groups of phase A (1, 4, 7, and so on) with N or S, as the compass needle shows. Then move the d-c lead to T_2, and mark the pole-phase groups of phase B; finally move the d-c

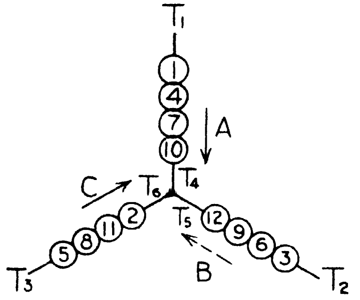


Fig. 3-6. Star connection

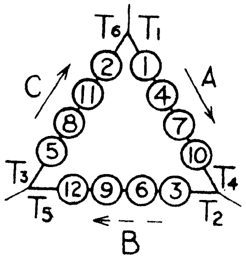


Fig. 3-7. Delta connection

test lead to T_3, and mark the pole-phase groups of phase C. It is advisable to use for the different phases different-colored chalk or to locate the markings of the 3 phases at different points; for example, the markings of phases A and C near both ends of the core, and the markings of phase B in the middle of the core. If the winding is correctly connected, the markings N and S will alternate all around the core. If there are two consecutive N's or S's, there is an error in the connections.

When the winding is delta-connected, one junction of the phase leads must be opened; for example, at the point T_1, T_6 (Fig. 3-7) where phases A and C are connected together. All other connections are maintained. The direct current must flow in all 3 phases in the same direction, i.e., either from the beginnings of the phases to their ends or vice versa to give a proper check. To accomplish this, first mark one d-c test lead and connect it to T_1 or T_6, at the opened point of the delta. Connect the other d-c test lead to that maintained or connected (T_2, T_4, or T_2, T_5) point of the delta which, at the same applied d-c voltage, gives the larger current. Then current flows only through one phase. Now mark the N and S magnetic polarities of this phase by using a compass, as described above. Then move the marked d-c lead to the point where the unmarked d-c lead was connected, and the unmarked d-c lead to the second maintained point of the delta. Again current flows through one phase only. Mark the polarities of this phase. Finally, move the marked d-c lead to the second maintained point of the delta, i.e., to the point where the unmarked d-c lead last was connected, and connect the unmarked d-c lead to T_6 if T_1 has been used at the start, or to T_1, if T_6 has been used at the start. Now current flows through the third of the 3 phases. Mark the polarities of this phase. As for the star connection, the winding is correctly connected, if N and S alternate throughout the whole winding. Note that the delta point T_1, T_6 has been used above only as an example. Any point of the delta can be opened for the test in consideration. (See Art. 3-7 about the checking of a finished 3-phase winding by a dummy rotor or a steel ball.)

3-13. Star (Wye "Y") and Delta (Δ) Connection. The 3 phases of a 3-phase winding can be connected in two different ways. Consider Fig. 3-5. The ends of the three phases T_4, T_5, and T_6 can be connected together at a common point called the "neutral point" leaving the phase beginnings as leads. This is shown schematically in Fig. 3-6. This kind of connection is the star or wye connection. Instead of connecting the ends of the phases to the neutral, the beginnings of the phases T_1, T_2, and T_3 can be connected together leaving the ends T_4, T_5, and T_6 as leads. Thus, the star (wye) connection of the 3 phases is obtained, when either the beginnings or the ends of the 3 phases are connected together and the 3 not connected wires are used as leads.

Fig. 3-7 shows schematically the delta connection of the 3 phases. Here the end of phase A (T_4) is connected with the beginnings of phase B_1 (T_2); the end of phase B (T_5) is connected with the beginning of phase C (T_3); and the end of phase C (T_6) is connected with the beginning of phase A (T_1). The leads are connected to the corners of the triangle. The delta connection can also be obtained if the end of phase A (T_4) is connected with the beginning of phase C (T_3); the end of phase C (T_6) is connected with the beginning of phase B (T_2); and the end of phase B (T_5) with the beginning of phase A (T_1).

3-14. Dual-voltage Connections. As mentioned in Art. 3-8, small motors are usually designed by the manufacturers to be used for different voltages; for example, for 110 and 220 volts, or for 220 and 440 volts. In this case, a series connection is used for the higher voltage, and a parallel connection for the lower voltage. The change from one voltage to the other is simplified when extra leads are brought out. If, for example, in Fig. 3-3b, the starts of groups 4 and 7 are brought out as leads, the connection (Fig. 3-3c) for 2 parallel circuits can be made easily, and the winding can be used for 2 voltages which have the ratio 2 to 1. The number of leads per phase is, in this case, 4 instead of 2 for the single-voltage winding. With 8 leads per phase, the series connection Fig. 3-3b can be readily changed to 2 as well as to 4 parallel circuits, and the winding can be used for 3 voltages in the ratios 4 to 2 to 1. In practice dual voltage windings connected either wye or delta have 9 leads (3 per phase) brought out. This is shown in Figs. 3-33 and 3-36.

3-15. Magnetic Unbalance and Equalizer Connections. A magnetic unbalance producing a side-pull may occur in electric machines due to bearing wear which makes the gap unequal around the armature or as a result of excessive side-pull on the pulley or of an unsymmetry in the winding. A series-connected winding has no corrective influence on the magnitude of the pull. A parallel-connected winding has the tendency to reduce the unbalance and the side-pull. In this respect, the connection with short jumpers is much more effective than that with long jumpers, especially in machines with lower numbers of poles. In a 4-pole or 6-pole machine connected with long jumpers, practically no corrective influence is produced by the parallel circuits. A considerable reduction of magnetic unbalance can be achieved by using short jumpers and equalizer connections. For this purpose, the parallel paths must be connected in the manner shown in Figs. 3-1c and 3-3c, but not as shown in Fig. 3-1d and 3-3d. Observe that in Fig. 3-1c, the pole-phase groups connected to T_1 and T_3, and those connected to T_1 and T_4 in Fig. 3-3c, lie opposite to each other in the core slots, i.e., 180 mechanical degrees apart. This is not the case in Figs. 3-1d and 3-3d. It will be found that in schematic diagrams (shown in the centers of the foregoing figures) of a 2-parallel connection, made according to Fig. 3-1c and 3-3c, there are always 2 pole-phase groups displaced by 180 mechanical degrees from each other. The equalizer connections are

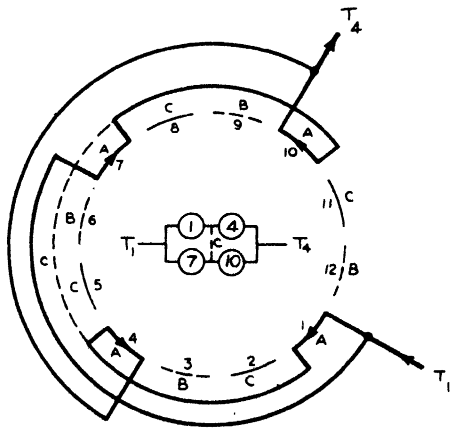


Fig. 3-8. 3-phase, 4-pole winding with 2 parallel paths and equalizer connections

then made between each 2 groups connected in series. Fig. 3-8 and 3-9 show the arrangement of the equalizer connections (c) for a 4-pole and 8-pole 3-phase winding with 2 parallel paths. Fig. 3-8 is the same as Fig. 3-3c, however, with equalizer connections.

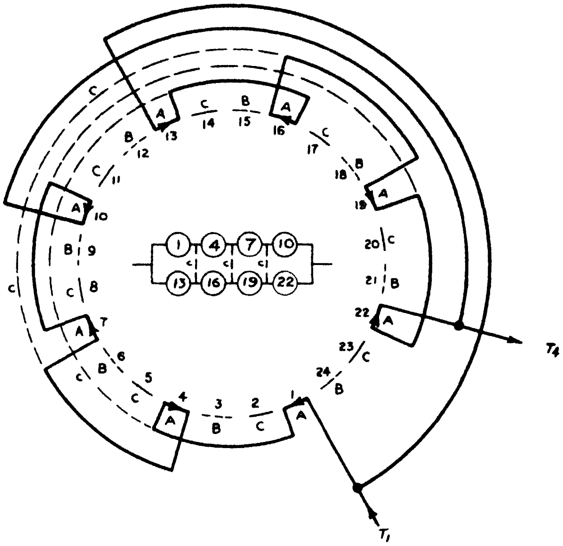


Fig. 3-9. 3-phase, 8-pole winding with 2 parallel paths and equalizer connections

The equalizer connections are used seldom, i.e., only in special cases in which a magnetic unbalance can be presumed, and then only for windings with 2 parallel paths. When the number of parallel paths is larger than 2,and the connection with short jumpers is used, a satisfactory corrective effect, due to the parallel paths, can be expected in the case of an unbalance. A magnetic unbalance is especially undesirable in induction motors, since these machines have small air gaps. However, most of the induction motors have squirrel-cage windings in the rotor, and these windings act as very effective equalizers with respect to magnetic unbalance.

TABLE 3-1 - STANDARD 2-PHASE CONNECTION DIAGRAMS AND TABLES FOR TOP-TO-TOP OR SHORT-JUMPER GROUP CONNECTION GIVEN IN THIS CHAPTER

No. of Poles	2	4	6	8
Connection Table No.	3-6	3-7	3-8	3-9
Connection	Connection Diagram No.			
1 circuit	3-10	3-13	3-18	3-24
2 circuit	3-11	3-14	3-19	3-25
3 circuit			3-20	
4 circuit		3-15		3-26
6 circuit			3-21	
8 circuit				3-27
1 & 2 circuit	3-12	3-16	3-22	3-28
2 & 4 circuit		3-17		3-29
3 & 6 circuit			3-23	
4 & 8 circuit				3-30

TABLE 3-2 - STANDARD 3-PHASE CONNECTION DIAGRAMS FOR TOP-TO-BOTTOM OR LONG-JUMPER GROUP CONNECTION GIVEN IN THIS CHAPTER

No. of Poles	4
Connection	Connection Diagram No.
1Y	3-31
2Y	3-32
1 & 2 Y	3-33
1Δ	3-34
2Δ	3-35
1 & 2Δ	3-36

TABLE 3-3 - STANDARD 3-PHASE CONNECTION DIAGRAMS AND TABLES FOR TOP-TO-TOP OR SHORT-JUMPER GROUP CONNECTION GIVEN IN THIS CHAPTER

No. of Poles	2	4	6	8	10	12	14
Connection Table No.	3-10	3-11	3-12	3-13	3-14	3-15	3-16
Connection	Connection Diagram No.						
1 Y	3-37	3-43	3-53	3-65	3-79	3-91	3-111
2 Y	3-38	3-44	3-54	3-66	3-80	3-92	3-112
3 Y			3-55			3-93	
4 Y		3-45		3-67		3-94	
5 Y					3-81		
6 Y			3-56			3-95	
7 Y							3-113
8 Y				3-68			
10 Y					3-82		
12 Y						3-96	
14 Y							3-114
1 & 2 Y	3-39	3-46	3-57	3-69	3-83	3-97	3-115
2 & 4 Y		3-47		3-70		3-98	
3 & 6 Y			3-58			3-99	
4 & 8 Y				3-71			
5 & 10 Y					3-84		
6 & 12 Y						3-100	
7 & 14 Y							3-116
1 Δ	3-40	3-48	3-59	3-72	3-85	3-101	3-117
2 Δ	3-41	3-49	3-60	3-73	3-86	3-102	3-118
3 Δ			3-61			3-103	
4 Δ		3-50		3-74		3-104	
5 Δ					3-87		
6 Δ			3-62			3-105	
7 Δ							3-119
8 Δ				3-75			
10 Δ					3-88		
12 Δ						3-106	
14 Δ							3-120
1 & 2 Δ	3-42	3-51	3-63	3-76	3-89	3-107	3-121
2 & 4 Δ		3-52		3-77		3-108	
3 & 6 Δ			3-64			3-109	
4 & 8 Δ				3-78			
5 & 10 Δ					3-90		
6 & 12 Δ						3-110	
7 & 14 Δ							3-122

TABLE OF SPP FOR 2-PHASE WINDINGS

(2 to 24 poles;
18 to 144 slots)

No. of Poles	2	4	6	8	10	12	14	16	18	20	22	24
No. of Pole-Phase Groups	4	8	12	16	20	24	28	32	36	40	44	48
No. of Slots	SPP											
18	4-1/2*	2-1/4*	1-1/2*									
20	5	2-1/2*	1-2/3	1-1/4*								
22	5-1/2*	2-3/4*	1-5/6*	1-3/8*	1-1/10							
24	6	3	2	1-1/2*	1-1/5							
26	6-1/2*	3-1/4*	2-1/6*	1-5/8*	1-3/10*	1-1/12*						
28	7	3-1/2*	2-1/3	1-3/4*	1-2/5	1-1/6*						
30	7-1/2*	3-3/4*	2-1/2*	1-7/8*	1-1/2*	1-1/4*	1-1/14*					
32	8	4	2-2/3	2	1-3/5	1-1/3	1-1/7					
34		4-1/4*	2-5/6*	2-1/8*	1-7/10*	1-5/12*	1-3/14*	1-1/16*				
36		4-1/2*	3	2-1/4*	1-4/5	1-1/2*	1-2/7	1-1/8*				
38		4-3/4*	3-1/6*	2-3/8*	1-9/10*	1-7/12*	1-5/14*	1-3/16*	1-1/18*			
40		5	3-1/3	2-1/2*	2	1-2/3	1-3/7	1-1/4*	1-1/9			
42		5-1/4*	3-1/2*	2-5/8*	2-1/10*	1-3/4*	1-1/2*	1-5/16*	1-1/6*	1-1/20*		
44		5-1/2*	3-2/3	2-3/4*	2-1/5	1-5/6*	1-4/7	1-3/8*	1-2/9	1-1/10*		
46		5-3/4*	3-5/6*	2-7/8*	2-3/10*	1-11/12*	1-9/14*	1-7/16*	1-5/18*	1-3/20*	1-1/22*	
48		6	4	3	2-2/5	2	1-5/7	1-1/2*	1-1/3	1-1/5	1-1/11	
50			4-1/6*	3-1/8*	2-1/2*	2-1/12*	1-11/14*	1-9/16*	1-7/18*	1-1/4*	1-3/22*	1-1/24*
52			4-1/3	3-1/4*	2-3/5	2-1/6*	1-6/7	1-5/8*	1-4/9	1-3/10*	1-2/11	1-1/12*
54			4-1/2*	3-3/8*	2-7/10*	2-1/4*	1-13/14*	1-11/16*	1-1/2*	1-7/20*	1-5/22*	1-1/8*
56			4-2/3	3-1/2*	2-4/5	2-1/3	2	1-3/4*	1-5/9	1-2/5	1-3/11	1-1/6*
58			4-5/16*	3-5/8*	2-9/10*	2-5/12*	2-1/14*	1-13/16*	1-11/18*	1-9/20*	1-7/22*	1-5/24*
60			5	3-3/4*	3	2-1/2*	2-1/7	1-7/8*	1-2/3	1-1/2*	1-4/11	1-1/4*
62				3-7/8*	3-1/10*	2-7/12*	2-3/14*	1-15/16*	1-13/18*	1-11/20*	1-9/22*	1-7/24*
64				4	3-1/5	2-2/3	2-2/7	2	1-7/9	1-3/5	1-5/11	1-1/3
66				4-1/8*	3-3/10*	2-3/4*	2-5/14*	2-1/16*	1-5/6*	1-13/20*	1-1/2*	1-3/8*
68				4-1/4*	3-2/5	2-5/6*	2-3/7	2-1/8*	1-8/9	1-7/10*	1-6/11	1-5/12*
70				4-3/8*	3-1/2*	2-11/12*	2-1/2*	2-3/16*	1-17/18*	1-3/4*	1-13/22*	1-11/24*
72				4-1/2*	3-3/5	3	2-4/7	2-1/4*	2	1-4/5	1-7/11	1-1/2*

74 **76** **78** **80**				4-5/8* 4-3/4*	3-7/10* 3-4/5 3-9/10* **4**	3-1/12* 3-1/6* 3-1/4* 3-1/3	2-9/14* 2-5/7 2-11/14* 2-6/7	2-5/16* 2-3/8* 2-7/16* 2-1/2*	2-1/18* 2-1/9 2-1/6* 2-2/9	1-17/20* 1-9/10* 1-19/20* **2**	1-15/22* 1-8/11 1-17/22* 1-9/11	1-13/24* 1-7/12* 1-5/8* 1-2/3
82 **84** **86** **88**					4-1/10* 4-1/5 4-3/10* 4-2/5	3-5/12* 3-1/2* 3-7/12* 3-2/3	2-13/14* **3** 3-1/14* 3-1/7	2-9/16* 2-5/8* 2-11/16* 2-3/4*	2-5/18* 2-1/3 2-7/18* 2-4/9	2-1/20* 2-1/10* 2-3/20* 2-1/5	1-19/22* 1-10/11 1-21/22* **2**	1-17/24* 1-3/4* 1-19/24* 1-5/6*
90 **92** **94** **96**					4-1/2*	3-3/4* 3-5/6* 3-11/12* **4**	3-3/14* 3-2/7 3-5/14* 3-3/7	2-13/16* 2-7/8* 2-15/16* **3**	2-1/2* 2-5/9 2-11/18* 2-2/3	2-1/4* 2-3/10* 2-7/20* 2-2/5	2-1/22* 2-1/11 2-3/22* 2-2/11	1-7/8* 1-11/12* 1-23/24* **2**
98 **100** **102** **104**						4-1/12* 4-1/6* 4-1/4* 4-1/3	3-1/2* 3-4/7 3-9/14* 3-5/7	3-1/16* 3-1/8* 3-3/16* 3-1/4*	2-13/18* 2-7/9 2-5/6* 2-8/9	2-9/20* 2-1/2* 2-11/20* 2-3/5	2-5/22* 2-3/11 2-7/22* 2-4/11	2-1/24* 2-1/12* 2-1/8* 2-1/6*
106 **108** **110** **112**							3-11/14* 3-6/7	3-5/16* 3-3/8* 3-7/16* 3-1/2*	2-17/18* **3** 3-1/18* 3-1/9	2-13/20* 2-7/10* 2-3/4* 2-4/5	2-9/22* 2-5/11 2-1/2* 2-6/11	2-5/24* 2-1/4* 2-7/24* 2-1/3
114 **116** **118** **120**								3-9/16*	3-1/6* 3-2/9 3-5/18* 3-1/3	2-17/20* 2-9/10* 2-19/20* **3**	2-13/22* 2-7/11 2-15/22* 2-8/11	2-3/8* 2-5/12* 2-11/24* 2-1/2*
122 **124** **126** **128**										3-1/20* 3-1/10* 3-3/20* 3-1/5	2-17/22* 2-9/11 2-19/22* 2-10/11	2-13/24* 2-7/12* 2-5/8* 2-2/3
130 **132** **134** **136**											2-21/22* **3** 3-1/22* 3-1/11	2-17/24* 2-3/4* 2-19/24* 2-5/6*
138 **140** **142** **144**												2-7/8* 2-11/12* 2-23/24* **3**

Figures in heavy type denote spp for the Integral-Slot Windings described in Chapter 3.

Figures in normal type denote spp for the Balanced Fractional-Slot Windings described in Chapter 4.

Figures marked by an asterisk denote spp for the Unbalanced Fractional-Slot Windings described in Chapter 5.

MASTER TABLE 3-5

TABLE OF SPP FOR 3-PHASE WINDINGS

(2 to 52 poles;
18 to 540 slots)

No. of Poles	2	4	6	8	10	12	14	16	18
No. of Pole-Phase Groups	6	12	18	24	30	36	42	48	54
No. of Slots	SPP								
18	3	1-1/2							
21	3-1/2	1-3/4	1-1/6*						
24	4	2	1-1/3*						
27	4-1/2	2-1/4	1-1/2	1-1/8					
30	5	2-1/2	1-2/3*	1-1/4					
33	5-1/2	2-3/4	1-5/6*	1-3/8	1-1/10				
✓36	6	3 ✓	2	1-1/2	1-1/5				
39	6-1/2	3-1/4	2-1/6*	1-5/8	1-3/10	1-1/12*			
42	7	3-1/2	2-1/3*	1-3/4	1-2/5	1-1/6*			
45	7-1/2	3-3/4	2-1/2	1-7/8	1-1/2	1-1/4	1-1/14		
48	8	4	2-2/3*	2	1-3/5	1-1/3*	1-1/7		
51	8-1/2	4-1/4	2-5/6*	2-1/8	1-7/10	1-5/12*	1-3/14	1-1/16	
54	9	4-1/2	3	2-1/4	1-4/5	1-1/2	1-2/7	1-1/8	
57	9-1/2	4-3/4	3-1/6*	2-3/8	1-9/10	1-7/12*	1-5/14	1-3/16	1-1/18*
60	10	5 ✓	3-1/3*	2-1/2	2	1-2/3*	1-3/7	1-1/4	1-1/9*
63	10-1/2	5-1/4	3-1/2	2-5/8	2-1/10	1-3/4	1-1/2	1-5/16	1-1/6*
66	11	5-1/2	3-2/3*	2-3/4	2-1/5	1-5/6*	1-4/7	1-3/8	1-2/9*
69	11-1/2	5-3/4	3-5/6*	2-7/8	2-3/10	1-11/12*	1-9/14	1-7/16	1-5/18*
72	12	6	4	3	2-2/5	2	1-5/7	1-1/2	1-1/3*
75		6-1/4	4-1/6*	3-1/8	2-1/2	2-1/12*	1-11/14	1-9/16	1-7/18*
78		6-1/2	4-1/3*	3-1/4	2-3/5	2-1/6*	1-6/7	1-5/8	1-4/9*
81		6-3/4	4-1/2	3-3/8	2-7/10	2-1/4	1-13/14	1-11/16	1-1/2
84		7	4-2/3*	3-1/2	2-4/5	2-1/3*	2	1-3/4	1-5/9*
87		7-1/4	4-5/6*	3-5/8	2-9/10	2-5/12*	2-1/14	1-13/16	1-11/18*
90		7-1/2	5	3-3/4	3	2-1/2	2-1/7	1-7/8	1-2/3*
93		7-3/4	5-1/6*	3-7/8	3-1/10	2-7/12*	2-3/14	1-15/16	1-13/18*
96		8	5-1/3*	4	3-1/5	2-2/3*	2-2/7	2	1-7/9*
99			5-1/2	4-1/8	3-3/10	2-3/4	2-5/14	2-1/16	1-5/6*
102			5-2/3*	4-1/4	3-2/5	2-5/6*	2-3/7	2-1/8	1-8/9*
105			5-5/6*	4-3/8	3-1/2	2-11/12*	2-1/2	2-3/16	1-17/18*

108			**6**	4-1/2	3-3/5	**3**	2-4/7	2-1/4	**2**
111			_6-1/6_*	4-5/8	3-7/10	_3-1/12_*	2-9/14	2-5/16	_2-1/18_*
114			_6-1/3_*	4-3/4	3-4/5	_3-1/6_*	2-5/7	2-3/8	_2-1/9_*
117			6-1/2	4-7/8	3-9/10	3-1/4	2-11/14	2-7/16	_2-1/6_*
120			_6-2/3_*	**5**	**4**	_3-1/3_*	2-6/7	2-1/2	_2-2/9_*
123			_6-5/6_*	5-1/8	4-1/10	_3-5/12_*	2-13/14	2-9/16	_2-5/18_*
126			**7**	5-1/4	4-1/5	3-1/2	**3**	2-5/8	_2-1/3_*
129			_7-1/6_*	5-3/8	4-3/10	_3-7/12_*	3-1/14	2-11/16	_2-7/18_*
132			_7-1/3_*	5-1/2	4-2/5	_3-2/3_*	3-1/7	2-3/4	_2-4/9_*
135			7-1/2	5-5/8	4-1/2	3-3/4	3-3/14	2-13/16	2-1/2
138			_7-2/3_*	5-3/4	4-3/5	_3-5/6_*	3-2/7	2-7/8	_2-5/9_*
141			_7-5/6_*	5-7/8	4-7/10	_3-11/12_*	3-5/14	2-15/16	_2-11/18_*
144			**8**	**6**	4-4/5	**4**	3-3/7	**3**	_2-2/3_*
147				6-1/8	4-9/10	_4-1/12_*	3-1/2	3-1/16	_2-13/18_*
150				6-1/4	**5**	_4-1/6_*	3-4/7	3-1/8	_2-7/9_*
153				6-3/8	5-1/10	4-1/4	3-9/14	3-3/16	_2-5/6_*
156				6-1/2	5-1/5	_4-1/3_*	3-5/7	3-1/4	_2-8/9_*
159				6-5/8	5-3/10	_4-5/12_*	3-11/14	3-5/16	_2-17/18_*
162				6-3/4	5-2/5	4-1/2	3-6/7	3-3/8	**3**
165				6-7/8	5-1/2	_4-7/12_*	3-13/14	3-7/16	_3-1/18_*
168				**7**	5-3/5	_4-2/3_*	**4**	3-1/2	_3-1/9_*
171					5-7/10	4-3/4	4-1/14	3-9/16	_3-1/6_*
174					5-4/5	_4-5/6_*	4-1/7	3-5/8	_3-2/9_*
177					5-9/10	_4-11/12_*	4-3/14	3-11/16	_3-5/18_*
180					**6**	**5**	4-2/7	3-3/4	_3-1/3_*
183					6-1/10	_5-1/12_*	4-5/14	3-13/16	_3-7/18_*
186					6-1/5	_5-1/6_*	4-3/7	3-7/8	_3-4/9_*
189					6-3/10	5-1/4	4-1/2	3-15/16	3-1/2
192					6-2/5	_5-1/3_*	4-4/7	**4**	_3-5/9_*
195					6-1/2	_5-5/12_*	4-9/14	4-1/16	_3-11/18_*
198						5-1/2	4-5/7	4-1/8	_3-2/3_*
201						_5-7/12_*	4-11/14	4-3/16	_3-13/18_*
204						_5-2/3_*	4-6/7	4-1/4	_3-7/9_*
207						5-3/4	4-13/14	4-5/16	_3-5/6_*
210						_5-5/6_*	**5**	4-3/8	_3-8/9_*
213						_5-11/12_*	5-1/14	4-7/16	_3-17/18_*
216						**6**	5-1/7	4-1/2	**4**
219							5-3/14	4-9/16	_4-1/18_*
222							5-2/7	4-5/8	_4-1/9_*
225							5-5/14	4-11/16	_4-1/6_*

Figures in heavy type denote spp for the Integral-Slot windings described in Chapters 3 and 6.
Figures in normal type denote spp for the Balanced Fractional-Slot windings described in Chapters 4, 6 and 7.
Figures in italics marked by an asterisk denote spp for the Unbalanced Fractional-Slot windings described in Chapters 5 and 8.

MASTER TABLE 3-5 (Continued)

TABLE OF SPP FOR 3-PHASE WINDINGS (Continued)

(2 to 52 poles;
18 to 540 slots)

No. of Poles	2	4	6	8	10	12	14	16	18
No. of Pole-Phase Groups	6	12	18	24	30	36	42	48	54
No. of Slots	SPP								
228							5-3/7	4-3/4	_4-2/9*_
231							5-1/2	4-13/16	_4-5/18*_
234								4-7/8	_4-1/3*_
237								4-15/16	_4-7/18*_
240								5	_4-4/9*_
243									4-1/2
246									_4-5/9*_
249									_4-11/18*_
252									_4-2/3*_
255									_4-13/18*_
258									_4-7/9*_
261									_4-5/6*_
264									_4-8/9*_
267									_4-17/18*_
270									5

Figures in heavy type denote spp for the Integral-Slot windings described in Chapters 3 and 6.
Figures in normal type denote spp for the Balanced Fractional-Slot windings described in Capters 4, 6 and 7.
Figures in italics marked by an asterisk denote spp for the Unbalanced Fractional-Slot windings described in Chapters 5 and 8.

MASTER TABLE 3-5 (Continued)

TABLE OF SPP FOR 3-PHASE WINDINGS (Continued)

(2 to 52 poles;
18 to 540 slots)

No. of Poles	20	22	24	26	28	30	32	34	36
No. of Pole-Phase Groups	60	66	72	78	84	90	96	102	108
No. of Slots	SPP								
63	1-1/20								
66	1-1/10								
69	1-3/20	1-1/22							
72	1-1/5	1-1/11							
75	1-1/4	1-3/22	_1-1/24*_						
78	1-3/10	1-2/11	_1-1/12*_						
81	1-7/20	1-5/22	1-1/8	1-1/26					
84	1-2/5	1-3/11	_1-1/6*_	1-1/13					
87	1-9/20	1-7/22	_1-5/24*_	1-3/26	1-1/28				
90	1-1/2	1-4/11	1-1/4	1-2/13	1-1/14				
93	1-11/20	1-9/22	_1-7/24*_	1-5/26	1-3/28	_1-1/30*_			
96	1-3/5	1-5/11	_1-1/3*_	1-3/13	1-1/7	_1-1/15*_			
99	1-13/20	1-1/2	1-3/8	1-7/26	1-5/28	1-1/10	1-1/32		
102	1-7/10	1-6/11	_1-5/12*_	1-4/13	1-3/14	_1-2/15*_	1-1/16		
105	1-3/4	1-13/22	_1-11/24*_	1-9/26	1-1/4	_1-1/6*_	1-3/32	1-1/34	
108	1-4/5	1-7/11	1-1/2	1-5/13	1-2/7	1-1/5	1-1/8	1-1/17	
111	1-17/20	1-15/22	_1-13/24*_	1-11/26	1-9/28	_1-7/30*_	1-5/32	1-3/34	_1-1/36*_
114	1-9/10	1-8/11	_1-7/12*_	1-6/13	1-5/14	_1-4/15*_	1-3/16	1-2/17	_1-1/18*_
117	1-19/20	1-17/22	1-5/8	1-1/2	1-11/28	1-3/10	1-7/32	1-5/34	_1-1/12*_
120	**2**	1-9/11	_1-2/3*_	1-7/13	1-3/7	_1-1/3*_	1-1/4	1-3/17	_1-1/9*_
123	2-1/20	1-19/22	_1-17/24*_	1-15/26	1-13/28	_1-11/30*_	1-9/32	1-7/34	_1-5/36*_
126	2-1/10	1-10/11	1-3/4	1-8/13	1-1/2	1-2/5	1-5/16	1-4/17	_1-1/6*_
129	2-3/20	1-21/22	_1-19/24*_	1-17/26	1-15/28	_1-13/30*_	1-11/32	1-9/34	_1-7/36*_
132	2-1/5	**2**	_1-5/6*_	1-9/13	1-4/7	_1-7/15*_	1-3/8	1-5/17	_1-2/9*_
135	2-1/4	2-1/22	1-7/8	1-19/26	1-17/28	1-1/2	1-13/32	1-11/34	1-1/4

Figures in heavy type denote spp for the Integral-Slot windings described in Chapters 3 and 6.
Figures in normal type denote spp for the Balanced Fractional-Slot windings described in Chapters 4, 6 and 7.
Figures in italics marked by an asterisk denote spp for the Unbalanced Fractional-Slot windings described in Chapters 5 and 8.

MASTER TABLE 3-5 (Continued)

TABLE OF SPP FOR 3-PHASE WINDINGS (Continued)

(2 to 52 poles;
18 to 540 slots)

No. of Poles	20	22	24	26	28	30	32	34	36
No. of Pole-Phase Groups	60	66	72	78	84	90	96	102	108
No. of Slots	SPP								
138	2-3/10	2-1/11	1-11/12*	1-10/13	1-9/14	1-8/15*	1-7/16	1-6/17	1-5/18*
141	2-7/20	2-3/22	1-23/24*	1-21/26	1-19/28	1-17/30*	1-15/32	1-13/34	1-11/36*
144	2-2/5	2-2/11	2	1-11/13	1-5/7	1-3/5	1-1/2	1-7/17	1-1/3*
147	2-9/20	2-5/22	2-1/24*	1-23/26	1-21/28	1-19/30*	1-17/32	1-15/34	1-13/36*
150	2-1/2	2-3/11	2-1/12*	1-12/13	1-11/14	1-2/3*	1-9/16	1-8/17	1-7/18*
153	2-11/20	2-7/22	2-1/8	1-25/26	1-23/28	1-7/10	1-19/32	1-1/2	1-5/12*
156	2-3/5	2-4/11	2-1/6*	2	1-6/7	1-11/15*	1-5/8	1-9/17	1-4/9*
159	2-13/20	2-9/22	2-5/24*	2-1/26	1-25/28	1-23/30*	1-21/32	1-19/34	1-17/36*
162	2-7/10	2-5/11	2-1/4	2-1/13	1-13/14	1-4/5	1-11/16	1-10/17	1-1/2
165	2-3/4	2-1/2	2-7/24*	2-3/26	1-27/28	1-5/6*	1-23/32	1-21/34	1-19/36*
168	2-4/5	2-6/11	2-1/3*	2-2/13	2	1-13/15*	1-3/4	1-11/17	1-5/9*
171	2-17/20	2-13/22	2-3/8	2-5/26	2-1/28	1-9/10	1-25/32	1-23/34	1-7/12*
174	2-9/10	2-7/11	2-5/12*	2-3/13	2-1/14	1-14/15*	1-13/16	1-12/17	1-11/18*
177	2-19/20	2-15/22	2-11/24*	2-7/26	2-3/28	1-29/30*	1-27/32	1-25/34	1-23/36*
180	3	2-8/11	2-1/2	2-4/13	2-1/7	2	1-7/8	1-13/17	1-2/3*
183	3-1/20	2-17/22	2-13/24*	2-9/26	2-5/28	2-1/30*	1-29/32	1-27/34	1-25/36*
186	3-1/10	2-9/11	2-7/12*	2-5/13	2-3/14	2-1/15*	1-15/16	1-14/17	1-13/18*
189	3-3/20	2-19/22	2-5/8	2-11/26	2-1/4	2-1/10	1-31/32	1-29/34	1-3/4
192	3-1/5	2-10/11	2-2/3*	2-6/13	2-2/7	2-2/15*	2	1-15/17	1-7/9*
195	3-1/4	2-21/22	2-17/24*	2-1/2	2-9/28	2-1/6*	2-1/32	1-31/34	1-29/36*
198	3-3/10	3	2-3/4	2-7/13	2-5/14	2-1/5	2-1/16	1-16/17	1-5/6*
201	3-7/20	3-1/22	2-19/24*	2-15/26	2-11/28	2-7/30*	2-3/32	1-33/34	1-31/36*
204	3-2/5	3-1/11	2-5/6 *	2-8/13	2-3/7	2-4/15*	2-1/8	2	1-8/9*
207	3-9/20	3-3/22	2-7/8	2-17/26	2-13/28	2-3/10	2-5/32	2-1/34	1-11/12*
210	3-1/2	3-2/11	2-11/12*	2-9/13	2-1/2	2-1/3*	2-3/16	2-1/17	1-17/18*
213	3-11/20	3-5/22	2-23/24*	2-19/26	2-15/28	2-11/30*	2-7/32	2-3/34	1-35/36*
216	3-3/5	3-3/11	3	2-10/13	2-4/7	2-2/5	2-1/4	2-2/17	2
219	3-13/20	3-7/22	3-1/24*	2-21/26	2-17/28	2-13/30*	2-9/32	2-5/34	2-1/36*
222	3-7/10	3-4/11	3-1/12*	2-11/13	2-9/14	2-7/15*	2-5/16	2-3/17	2-1/18*
225	3-3/4	3-9/22	3-1/8	2-23/26	2-19/28	2-1/2	2-11/32	2-7/34	2-1/12*

228	3-4/5	3-5/11	_3-1/6_*	2-12/13	2-5/7	_2-8/15_*	2-3/8	2-4/17	_2-1/9_*
231	3-17/20	3-1/2	_3-5/24_*	2-25/26	2-21/28	_2-17/30_*	2-13/32	2-9/34	_2-5/36_*
234	3-9/10	3-6/11	3-1/4	**3**	2-11/14	2-3/5	2-7/16	2-5/17	_2-1/6_
237	3-19/20	3-13/22	_3-7/24_*	3-1/26	2-23/28	_2-19/30_*	2-15/32	2-11/34	_2-7/36_*
240	**4**	3-7/11	_3-1/3_*	3-1/13	2-6/7	_2-2/3_*	2-1/2	2-6/17	_2-2/9_*
243	4-1/20	3-15/22	3-3/8	3-3/26	2-25/28	2-7/10	2-17/32	2-13/34	2-1/4
246	4-1/10	3-8/11	_3-5/12_*	3-2/13	2-13/14	_2-11/15_*	2-9/16	2-7/17	_2-5/18_*
249	4-3/20	3-17/22	_3-11/24_*	3-5/26	2-27/28	_2-23/30_*	2-19/32	2-15/34	_2-11/36_*
252	4-1/5	3-9/11	3-1/2	3-3/13	**3**	2-4/5	2-5/8	2-8/17	_2-1/3_*
255	4-1/4	3-19/22	_3-13/24_*	3-7/26	3-1/28	_2-5/6_*	2-21/32	2-1/2	_2-13/36_*
258	4-3/10	3-10/11	_3-7/12_*	3-4/13	3-1/14	_2-13/15_*	2-11/16	2-9/17	_2-7/18_*
261	4-7/20	3-21/22	3-5/8	3-9/26	3-3/28	2-9/10	2-23/32	2-19/34	_2-5/12_*
264	4-2/5	**4**	_3-2/3_*	3-5/13	3-1/7	_2-14/15_*	2-3/4	2-10/17	_2-4/9_*
267	4-9/20	4-1/22	_3-17/24_*	3-11/26	3-5/28	_2-29/30_*	2-25/32	2-21/34	_2-17/36_*
270	4-1/2	4-1/11	3-3/4	3-6/13	3-3/14	**3**	2-13/16	2-11/17	2-1/2
273	4-11/20	4-3/22	_3-19-24_*	3-1/2	3-1/4	_3-1/30_*	2-27/32	2-23/34	_2-19/36_*
276	4-3/5	4-2/11	_3-5/6_*	3-7/13	3-2/7	_3-1/15_*	2-7/8	2-12/17	_2-5/9_*
279	4-13/20	4-5/22	3-7/8	3-15/26	3-9/28	3-1/10	2-29/32	2-25/34	_2-7/12_
282	4-7/10	4-3/11	_3-11/12_*	3-8/13	3-5/14	_3-2/15_*	2-15/16	2-13/17	_2-11/18_*
285	4-3/4	4-7/22	_3-23/24_*	3-17/26	3-11/28	_3-1/6_*	2-31/32	2-27/34	_2-23/36_*
288		4-4/11	**4**	3-9/13	3-3/7	3-1/5	**3**	2-14/17	_2-2/3_*
291		4-9/22	_4-1/24_*	3-19/26	3-13/28	_3-7/30_*	3-1/32	2-29/34	_2-25/36_*
294		4-5/11	_4-1/12_*	3-10/13	3-1/2	_3-4/15_*	3-1/16	2-15/17	_2-13/18_*
297		4-1/2	4-1/8	3-21/26	3-15/28	3-3/10	3-3/32	2-31/34	2-3/4
300			_4-1/6_*	3-11/13	3-4/7	_3-1/3_*	3-1/8	2-16/17	_2-7/9_*
303			_4-5/24_*	3-23/26	3-17/28	_3-11/30_*	3-5/32	2-33/34	_2-29/36_*
306			4-1/4	3-12/13	3-9/14	3-2/5	3-3/16	**3**	_2-5/6_*
309			_4-7/24_*	3-25/26	3-19/28	_3-13/30_*	3-7/32	3-1/34	_2-31/36_*
312			_4-1/3_*	**4**	3-5/7	_3-7/15_*	3-1/4	3-1/17	_2-8/9_
315			4-3/8	4-1/26	3-21/28	3-1/2	3-9/32	3-3/34	_2-11/12_*
318			_4-5/12_*	4-1/13	3-11/14	_3-8/15_*	3-5/16	3-2/17	_2-17/18_*
321			_4-11/24_*	4-3/26	3-23/28	_3-17/30_*	3-11/32	3-5/34	_2-35/36_*
324			4-1/2	4-2/13	3-6/7	3-3/5	3-3/8	3-3/17	**3**
327				4-5/26	3-25/28	_3-19/30_*	3-13/32	3-7/34	_3-1/36_*
330				4-3/13	3-13/14	_3-2/3_*	3-7/16	3-4/17	_3-1/18_*
333				4-7/26	3-27/28	3-7/10	3-15/32	3-9/34	_3-1/12_*
336				4-4/13	**4**	_3-11/15_*	3-1/2	3-5/17	_3-1/9_*
339				4-9/26	4-1/28	_3-23/30_*	3-17/32	3-11/34	_3-5/36_*
342				4-5/13	4-1/14	3-4/5	3-9/16	3-6/17	_3-1/6_*
345				4-11/26	4-3/28	_3-5/6_*	3-19/32	3-13/34	_3-7/36_*

Figures in heavy type denote spp for the Integral-Slot windings described in Chapters 3 and 6.
Figures in normal type denote spp for the Balanced Fractional-Slot windings described in Chapters 4, 6 and 7.
Figures in italics marked by an asterisk denote spp for the Unbalanced Fractional-Slot windings described in Chapters 5 and 8.

MASTER TABLE 3-5 (Continued)

TABLE OF SPP FOR 3-PHASE WINDINGS (Continued)

(2 to 52 poles;
18 to 540 slots)

No. of Poles	20	22	24	26	28	30	32	34	36
No. of Pole-Phase Groups	60	66	72	78	84	90	96	102	108
No. of Slots	SPP								
348				4-6/13	4-1/7	3-13/15 *	3-5/8	3-7/17	3-2/9*
351				4-1/2	4-5/28	3-9/10	3-21/32	3-15/34	3-1/4
354					4-3/14	3-14/15*	3-11/16	3-8/17	3-5/18*
357					4-1/4	3-29/30*	3-23/32	3-1/2	3-11/36*
360					4-2/7	4	3-3/4	3-9/17	3-1/3*
363					4-9/28	4-1/30*	3-25/32	3-19/34	3-13/36*
366					4-5/14	4-1/15*	3-13/16	3-10/17	3-7/18*
369					4-11/28	4-1/10	3-27/32	3-21/34	3-5/12 *
372					4-3/7	4-2/15*	3-7/8	3-11/17	3-4/9*
375					4-13/28	4-1/6*	3-29/32	3-23/34	3-17/36*
378					4-1/2	4-1/5	3-15/16	3-12/17	3-1/2
381						4-7/30*	3-31/32	3-25/34	3-19/36*
384						4-4/15*	4	3-13/17	3-5/9*
387						4-3/10	4-1/32	3-27/34	3-7/12*
390						4-1/3*	4-1/16	3-14/17	3-11/18*
393						4-11/30*	4-3/32	3-29/34	3-23/36*
396						4-2/5	4-1/8	3-15/17	3-2/3*
399						4-13/30*	4-5/32	3-31/34	3-25/36*
402						4-7/15*	4-3/16	3-16/17	3-13/18*
405						4-1/2	4-7/32	3-33/34	3-3/4
408							4-1/4	4	3-7/9*
411							4-9/32	4-1/34	3-29/36*
414							4-5/16	4-1/17	3-5/6*
417							4-11/32	4-3/34	3-31/36*
420							4-3/8	4-2/17	3-8/9*
423							4-13/32	4-5/34	3-11/12*
426							4-7/16	4-3/17	3-17/18*
429							4-15/32	4-7/34	3-35/36*
432							4-1/2	4-4/17	4
435								4-9/34	4-1/36*

438 **441** **444** **447** **450**								4-5/17 4-11/34 4-6/17 4-13/34 4-7/17	_4-1/18*_ _4-1/12*_ _4-1/9*_ _4-5/36*_ _4-1/6*_
453 **456** **459** **462** **465**								4-15/34 4-8/17 4-1/2	_4-7/36*_ _4-2/9*_ 4-1/4 _4-5/18*_ _4-11/36*_
468 **471** **474** **477** **480**									_4-1/3*_ _4-13/36*_ _4-7/18*_ _4-5/12*_ _4-4/9*_
483 **486**									_4-17/36*_ 4-1/2

Figures in heavy type denote spp for the Integral-Slot windings described in Chapters 3 and 6.
Figures in normal type denote spp for the Balanced Fractional-Slot windings described in Chapters 3, 6 and 7.
Figures in italics marked by an asterisk denote spp for the Unbalanced Fractional-Slot windings described in Chapters 5 and 8.

MASTER TABLE 3-5 (Continued)

TABLE OF SPP FOR 3-PHASE WINDINGS (Continued)

(2 to 52 poles;
18 to 540 slots)

No. of Poles	38	40	42	44	46	48	50	52
No. of Pole-Phase Groups	114	120	126	132	138	144	150	156
No. of Slots	SPP							
117	1-1/38							
120	1-1/19							
123	1-3/38	1-1/40						
126	1-2/19	1-1/20						
129	1-5/38	1-3/40	1-1/42*					
132	1-3/19	1-1/10	1-1/21*					
135	1-7/38	1-1/8	1-1/14	1-1/44				
138	1-4/19	1-3/20	1-2/21*	1-1/22				
141	1-9/38	1-7/40	1-5/42*	1-3/44	1-1/46			
144	1-5/19	1-1/5	1-1/7	1-1/11	1-1/23			
147	1-11/38	1-9/40	1-1/6*	1-5/44	1-3/46	1-1/48*		
150	1-6/19	1-1/4	1-4/21*	1-3/22	1-2/23	1-1/24*		
153	1-13/38	1-11/40	1-3/14	1-7/44	1-5/46	1-1/16	1-1/50	
156	1-7/19	1-3/10	1-5/21*	1-2/11	1-3/23	1-1/12*	1-1/25	
159	1-15/38	1-13/40	1-11/42*	1-9/44	1-7/46	1-5/48*	1-3/50	1-1/52
162	1-8/19	1-7/20	1-2/7	1-5/22	1-4/23	1-1/8	1-2/25	1-1/26
165	1-17/38	1-3/8	1-13/42*	1-1/4	1-9/46	1-7/48*	1-1/10	1-3/52
168	1-9/19	1-2/5	1-1/3*	1-3/11	1-5/23	1-1/6*	1-3/25	1-1/13
171	1-1/2	1-17/40	1-5/14	1-13/44	1-11/46	1-3/16	1-7/50	1-5/52
174	1-10/19	1-9/20	1-8/21*	1-7/22	1-6/23	1-5/24*	1-4/25	1-3/26
177	1-21/38	1-19/40	1-17/42*	1-15/44	1-13/46	1-11/48*	1-9/50	1-7/52
180	1-11/19	1-1/2	1-3/7	1-4/11	1-7/23	1-1/4	1-1/5	1-2/13
183	1-23/38	1-21/40	1-19/42*	1-17/44	1-15/46	1-13/48*	1-11/50	1-9/52
186	1-12/19	1-11/20	1-10/21*	1-9/22	1-8/23	1-7/24*	1-6/25	1-5/26
189	1-25/38	1-23/40	1-1/2	1-19/44	1-17/46	1-5/16	1-13/50	1-11/52
192	1-13/19	1-3/5	1-11/21*	1-5/11	1-9/23	1-1/3*	1-7/25	1-3/13
195	1-27/38	1-5/8	1-23/42*	1-21/44	1-19/46	1-17/48*	1-3/10	1-1/4

198	1-14/19	1-13/20	1-4/7	1-1/2	1-10/23	1-3/8	1-8/25	1-7/26
201	1-29/38	1-27/40	_1-25/42*_	1-23/44	1-21/46	_1-19/48*_	1-17/50	1-15/52
204	1-15/19	1-7/10	_1-13/21*_	1-6/11	1-11/23	_1-5/12*_	1-9/25	1-4/13
207	1-31/38	1-29/40	1-9/14	1-25/44	1-23/46	1-7/16	1-19/50	1-17/52
210	1-16/19	1-3/4	_1-2/3*_	1-13/22	1-12/23	_1-11/24*_	1-2/5	1-9/26
213	1-33/38	1-31/40	_1-29/42*_	1-27/44	1-25/46	_1-23/48*_	1-21/50	1-19/52
216	1-17/19	1-4/5	1-5/7	1-7/11	1-13/23	1-1/2	1-11/25	1-5/13
219	1-35/38	1-33/40	_1-31/42*_	1-29/44	1-27/46	_1-25/48*_	1-23/50	1-21/52
222	1-18/19	1-17/20	_1-16/24*_	1-15/22	1-14/23	_1-13/24*_	1-12/25	1-11/26
225	1-37/38	1-7/8	1-11/14	1-31/44	1-29/46	1-9/16	1-1/2	1-23/52
228	**2**	1-9/10	_1-17/21*_	1-8/11	1-15/23	_1-7/12*_	1-13/25	1-6/13
231	2-1/38	1-37/40	_1-5/6*_	1-3/4	1-31/46	_1-29/48*_	1-27/50	1-25/52
234	2-1/19	1-19/20	1-6/7	1-17/22	1-16/23	1-5/8	1-14/25	1-1/2
237	2-3/38	1-39/40	_1-37/42*_	1-35/44	1-33/46	_1-31/48*_	1-29/50	1-27/52
240	2-2/19	**2**	_1-19/21*_	1-9/11	1-17/23	_1-2/3*_	1-3/5*	1-7/13
243	2-5/38	2-1/40	1-13/14	1-37/44	1-35/46	1-11/16	1-31/50	1-29/52
246	2-3/19	2-1/20	_1-20/21*_	1-19/22	1-18/23	_1-17/24*_	1-16/25	1-15/26
249	2-7/38	2-3/40	_1-41/42*_	1-39/44	1-37/46	_1-35/48*_	1-33/50	1-31/52
252	2-4/19	2-1/10	**2**	1-10/11	1-19/23	1-3/4	1-17/25	1-8/13
255	2-9/38	2-1/8	_2-1/42*_	1-41/44	1-39/46	_1-37/48*_	1-7/10	1-33/52
258	2-5/19	2-3/20	_2-1/21*_	1-21/22	1-20/23	_1-19/24*_	1-18/25	1-17/26
261	2-11/38	2-7/40	2-1/14	1-43/44	1-41/46	1-13/16	1-37/50	1-35/52
264	2-6/19	2-1/5	_2-2/21*_	**2**	1-21/23	_1-5/6*_	1-19/25	1-9/13
267	2-13/38	2-9/40	_2-5/42*_	2-1/44	1-43/46	_1-41/48*_	1-39/50	1-37/52
270	2-7/19	2-1/4	2-1/7	2-1/22	1-22/23	1-7/8	1-4/5	1-19/26
273	2-15/38	2-11/40	2-1/6	2-3/44	1-45/46	_1-43/48*_	1-41/50	1-3/4
276	2-8/19	2-3/10	_2-4/21*_	2-1/11	**2**	_1-11/12*_	1-21/25	1-10/13
279	2-17/38	2-13/40	2-3/14	2-5/44	2-1/46	1-15/16	1-43/50	1-41/52
282	2-9/19	2-7/20	_2-5/21*_	2-3/22	2-1/23	_1-23/24*_	1-22/25	1-21/26
285	2-1/2	2-3/8	_2-11/42*_	2-7/44	2-3/46	_1-47/48*_	1-9/10	1-43/52
288	2-10/19	2-2/5	2-2/7	2-2/11	2-2/23	**2**	1-23/25	1-11/13
291	2-21/38	2-17/40	_2-13/42*_	2-9/44	2-5/46	_2-1/48*_	1-47/50	1-45/52
294	2-11/19	2-9/20	_2-1/3*_	2-5/22	2-3/23	_2-1/24*_	1-24/25	1-23/26
297	2-23/38	2-19/40	2-5/14	2-1/4	2-7/46	2-1/16	1-49/50	1-47/52
300	2-12/19	2-1/2	_2-8/21*_	2-3/11	2-4/23	_2-1/12*_	**2**	1-12/13
303	2-25/38	2-21/40	_2-17/42*_	2-13/44	2-9/46	_2-5/48*_	2-1/50	1-49/52
306	2-13/19	2-11/20	2-3/7	2-7/22	2-5/23	2-1/8	2-1/25	1-25/26
309	2-27/38	2-23/40	_2-19/42*_	2-15/44	2-11/46	_2-7/48*_	2-3/50	1-51/52
312	2-14/19	2-3/5	_2-10/21*_	2-4/11	2-6/23	_2-1/6*_	2-2/25	**2**
315	2-29/38	2-5/8	2-1/2	2-17/44	2-13/46	2-3/16	2-1/10	2-1/52

Figures in heavy type denote spp for the Integral-Slot windings described in Chapters 3 and 6.
Figures in normal type denote spp for the Balanced Fractional-Slot windings described in Chapters 4, 6 and 7.
Figures in italics marked by an asterisk denote spp for the Unbalanced Fractional-Slot windings described in Chapters 5 and 8.

MASTER TABLE 3-5 (Continued)

TABLE OF SPP FOR 3-PHASE WINDINGS (Continued)

(2 to 52 poles;
18 to 540 slots)

No. of Poles	38	40	42	44	46	48	50	52
No. of Pole-Phase Groups	114	120	126	132	138	144	150	156
No. of Slots	SPP							
318	2-15/19	2-13/20	*2-11/21**	2-9/22	2-7/23	*2-5/24**	2-3/25	2-1/26
321	2-31/38	2-27/40	*2-23/42**	2-19/44	2-15/46	*2-11/48**	2-7/50	2-3/52
324	2-16/19	2-7/10	2-4/7	2-5/11	2-8/23	2-1/4	2-4/25	2-1/13
327	2-33/38	2-29/40	*2-25/42**	2-21/44	2-17/46	*2-13/48**	2-9/50	2-5/52
330	2-17/19	2-3/4	*2-13/21**	2-1/2	2-9/23	*2-7/24**	2-1/5	2-3/26
333	2-35/38	2-31/40	2-9/14	2-23/44	2-19/46	2-5/16	2-11/50	2-7/52
336	2-18/19	2-4/5	*2-2/3**	2-6/11	2-10/23	*2-1/3**	2-6/25	2-2/13
339	2-37/38	2-33/40	*2-29/42**	2-25/44	2-21/46	*2-17/48**	2-13/50	2-9/52
342	3	2-17/20	2-5/7	2-13/22	2-11/23	2-3/8	2-7/25	2-5/26
345	3-1/38	2-7/8	*2-31/42**	2-27/44	2-1/2	*2-19/48**	2-3/10	2-11/52
348	3-1/19	2-9/10	*2-16/21**	2-7/11	2-12/23	*2-5/12**	2-8/25	2-3/13
351	3-3/38	2-37/40	2-11/14	2-29/44	2-25/46	2-7/16	2-17/50	2-1/4
354	3-2/19	2-19/20	*2-17/21**	2-15/22	2-13/23	*2-11/24**	2-9/25	2-7/26
357	3-5/38	2-39/40	*2-5/6**	2-31/44	2-27/46	*2-23/48**	2-19/50	2-15/52
360	3-3/19	3	2-6/7	3-8/11	2-14/23	2-1/2	2-2/5	2-4/13
363	3-7/38	3-1/40	*2-37/42**	2-3/4	2-29/46	*2-25/48**	2-21/50	2-17/52
366	3-4/19	3-1/20	*2-19/21**	2-17/22	2-15/23	*2-13/24**	2-11/25	2-9/26
369	3-9/38	3-3/40	2-13/14	2-35/44	2-31/46	2-9/16	2-23/50	2-19/52
372	3-5/19	3-1/10	*2-20/21**	2-9/11	2-16/23	*2-7/12**	2-12/25	2-5/13
375	2-11/38	3-1/8	*2-41/42**	2-37/44	2-33/46	*2-29/48**	2-1/2	2-21/52
378	3-6/19	3-3/20	3	2-19/22	2-17/23	2-5/8	2-13/25	2-11/26
381	3-13/38	3-7/40	*3-1/42**	2-39/44	2-35/46	*2-31/48**	2-27/50	2-23/52
384	3-7/19	3-1/5	*3-1/21**	2-10/11	2-18/23	*2-2/3**	2-14/25	2-6/13
387	3-15/38	3-9/40	3-1/14	2-41/44	2-37/46	2-11/16	2-29/50	2-25/52
390	3-8/19	3-1/4	*3-2/21**	2-21/22	2-19/23	*2-17/24**	2-3/5	2-13/26
393	3-17/38	3-11/40	*3-5/42**	2-43/44	2-39/46	*2-35/48**	2-31/50	2-27/52
396	3-9/19	3-3/10	2-1/7	3	2-20/23	2-3/4	2-16/25	2-7/13
399	3-1/2	3-13/40	*3-1/6**	3-1/44	2-41/46	*2-37/48**	2-33/50	2-29/52
402	3-10/19	3-7/20	*3-4/21**	3-1/22	2-21/23	*2-19/24**	2-17/25	2-15/26
405	3-21/38	3-3/8	3-3/14	3-3/44	2-43/46	2-13/16	2-7/10	2-31/52

408	3-11/19	3-2/5	_3-5/21*_	3-1/11	2-22/23	_2-5/6*_	2-18/25	2-8/13
411	3-23/38	3-17/40	_3-11/42*_	3-5/44	2-45/46	_2-41/48*_	2-37/50	2-33/52
414	3-12/19	3-9/20	3-2/7	3-3/22	**3**	2-7/8	2-19/25	2-17/26
417	3-25/38	3-19/40	_3-13/42*_	3-7/44	3-1/46	_2-43/48*_	2-39/50	2-35/52
420	3-13/19	3-1/2	_3-1/3*_	3-2/11	3-1/23	_2-11/12*_	2-4/5	2-9/13
423	3-27/38	3-21/40	3-5/14	3-9/44	3-3/46	2-15/16	2-41/50	2-37/52
426	3-14/19	3-11/20	_3-8/21*_	3-5/22	3-2/23	_2-23/24*_	2-21/25	2-19/26
429	3-29/38	3-23/40	_3-17/42*_	3-1/4	3-5/46	_2-47/48*_	2-43/50	2-3/4
432	3-15/19	3-3/5	3-3/7	3-3/11	3-3/23	**3**	2-22/25	2-10/13
435	3-31/38	3-5/8	_3-19/42*_	3-13/44	3-7/46	_3-1/48*_	2-9/10	2-41/52
438	3-16/19	3-13/20	_3-10/21*_	3-7/22	3-4/23	_3-1/24*_	2-23/25	2-21/26
441	3-33/38	3-27/40	3-1/2	3-15/44	3-9/46	3-1/16	2-47/50	2-43/52
444	3-17/19	3-7/10	_3-11/21*_	3-4/11	3-5/23	_3-1/12*_	2-24/25	2-11/13
447	3-35/38	3-29/40	_3-23/42*_	3-17/44	3-11/46	_3-5/48*_	2-49/50	2-45/52
450	3-18/19	3-3/4	3-4/7	3-9/22	3-6/23	3-1/8	**3**	2-23/26
453	3-37/38	3-31/40	_3-25/42*_	3-19/44	3-13/46	_3-7/48*_	3-1/50	2-47/52
456	**4**	3-4/5	_3-13/21*_	3-5/11	3-7/23	_3-1/6*_	3-1/25	2-12/13
459	4-1/38	3-33/40	3-9/14	3-21/44	3-15/46	3-3/16	3-3/50	2-49/52
462	4-1/19	3-17/20	_3-2/3 *_	3-1/2	3-8/23	_3-5/24*_	3-2/25	2-25/26
465	4-3/38	3-7/8	_3-29/42*_	3-23/44	3-17/46	_3-11/48*_	3-1/10	2-51/52
468	4-2/19	3-9/10	3-5/7	3-6/11	3-9/23	3-1/4	3-3/25	**3**
471	4-5/38	3-37/40	_3-31/42*_	3-25/44	3-19/46	_3-13/48*_	3-7/50	3-1/52
474	4-3/19	3-19/20	_3-16/21*_	3-13/22	3-10/23	_3-7/24*_	3-4/25	3-1/26
477	4-7/38	3-39/40	3-11/14	3-27/44	3-21/46	3-5/16	3-9/50	3-3/52
480	4-4/19	**4**	_3-17/21*_	3-7/11	3-11/23	_3-1/3 *_	3-1/5	3-1/13
483	4-9/38	4-1/40	_3-5/6 *_	3-29/44	3-23/46	_3-17/48*_	3-11/50	3-5/52
486	4-5/19	4-1/20	3-6/7	3-15/22	3-12/23	3-3/8	3-6/25	3-3/26
489	4-11/38	4-3/40	_3-37/42*_	3-31/44	3-25/46	_3-19/48*_	3-13/50	3-7/52
492	4-6/19	4-1/10	_3-19/21*_	3-8/11	3-13/23	_3-5/12*_	3-7/25	3-2/13
495	4-13/38	4-1/8	3-13/14	3-3/4	3-27/46	3-7/16	3-3/10	3-9/52
498	4-7/19	4-3/20	_3-20/21*_	3-17/22	3-14/23	_3-11/24*_	3-8/25	3-5/26
501	4-15/38	4-7/40	_3-41/42*_	3-35/44	3-29/46	_3-23/48*_	3-17/50	3-11/52
504	4-8/19	4-1/5	**4**	3-9/11	3-15/23	3-1/2	3-9/25	3-3/13
507	4-17/38	4-9/40	_4-1/42 *_	3-37/44	3-31/46	_3-25/48*_	3-19/50	3-1/4
510	4-9/19	4-1/4	_4-1/21 *_	3-19/22	3-16/23	_3-13/24*_	3-2/5	3-7/26
513	4-1/2	4-11/40	4-1/14	3-39/44	3-33/46	3-9/16	3-21/50	3-15/52
516		4-3/10	_4-2/21 *_	3-10/11	3-17/23	_3-7/12 *_	3-11/25	3-4/13
519		4-13/40	_4-5/42 *_	3-41/44	3-35/46	_3-29/48 *_	3-23/50	3-7/52
522		4-7/20	4-1/7	3-21/22	3-18/23	3-5/8	3-12/25	3-9/26
525		4-3/8	_4-1/6 *_	3-43/44	3-37/46	_3-31/48 *_	3-1/2	3-19/52

Figures in heavy type denote spp for the Integral-Slot windings described in Chapters 3 and 6.
Figures in normal type denote spp for the Balanced Fractional-Slot windings described in Chapters 4, 6 and 7.
Figures in italics marked by an asterisk denote spp for the Unbalanced Fractional-Slot windings described in Chapters 5 and 8.

MASTER TABLE 3-5 (Continued)

TABLE OF SPP FOR 3-PHASE WINDINGS (Continued)

(2 to 52 poles;
18 to 540 slots)

No. of Poles	38	40	42	44	46	48	50	52
No. of Pole-Phase Groups	114	120	126	132	138	144	150	156
No. of Slots	SPP							
528		4-2/5	*4-4/21**	**4**	3-19/23	*3-2/3 **	3-13/25	3-5/13
531		4-17/40	4-3/14	4-1/44	3-39/46	3-11/16	3-27/50	3-21/52
534		4-9/20	*4-5/21**	4-1/22	3-20/23	*3-17/24**	3-14/25	3-11/26
537		4-19/40	*4-11/42**	4-3/44	3-41/46	*3-35/48**	3-29/50	3-23/52
540		4-1/2	4-2/7	4-1/11	3-21/23	3-3/4	3-3/5	3-6/13

Figures in heavy type denote spp for the Integral-Slot windings described in Chapters 3 and 6.
Figures in normal type denote spp for the Balanced Fractional-Slot windings described in Chapters 4, 6 and 7.
Figures in italics marked by an asterisk denote spp for the Unbalanced Fractional-Slot windings described in Chapters 5 and 8.

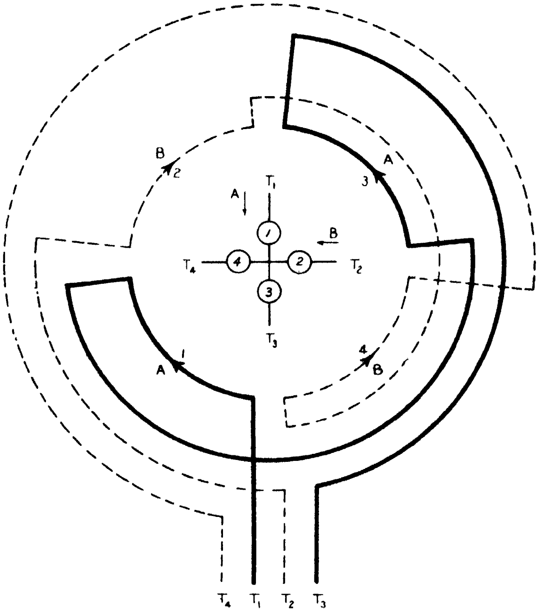


Fig. 3-10. 2-pole, 2-phase, series connection diagram T-T

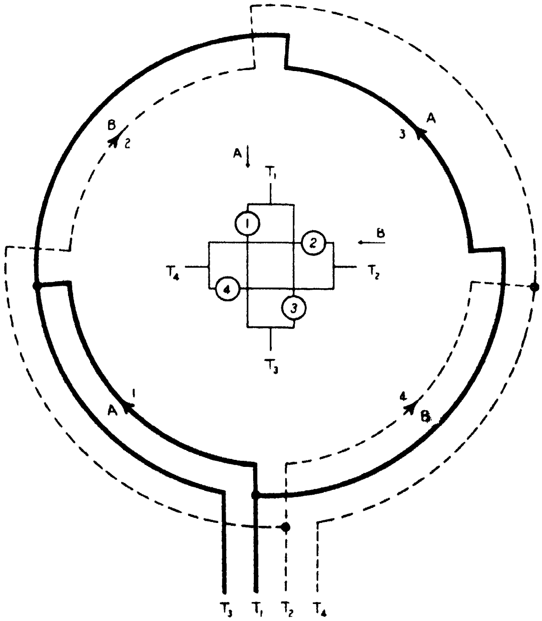


Fig. 3-11. 2-pole, 2-phase, 2-parallel connection diagram

TABLE 3-6

2-POLE 2-PHASE CONNECTION TABLE

(Reference Connection Diagrams Figs. 3-10, 3-11)

Phase	Connections		Leads	
A	Series	S_1 $F_1 \rightarrow F_3$ S_3	$T_1 \rightarrow S_1$	$T_3 \rightarrow S_3$
	2-parallel	S_1 $F_1 \Vert F_3$ S_3	$T_1 \rightarrow S_1 \rightarrow F_3$	$T_3 \rightarrow F_1 \rightarrow S_3$
B	Series	S_2 $F_2 \rightarrow F_4$ S_4	$T_2 \rightarrow S_2$	$T_4 \rightarrow S_4$
	2-parallel	S_2 $F_2 \Vert F_4$ S_4	$T_2 \rightarrow S_2 \rightarrow F_4$	$T_4 \rightarrow F_2 \rightarrow S_4$

S = start of a group.

F = finish of a group.

→ connected to start or finish of a group.

$\Vert$ spot for change with respect to series connection.

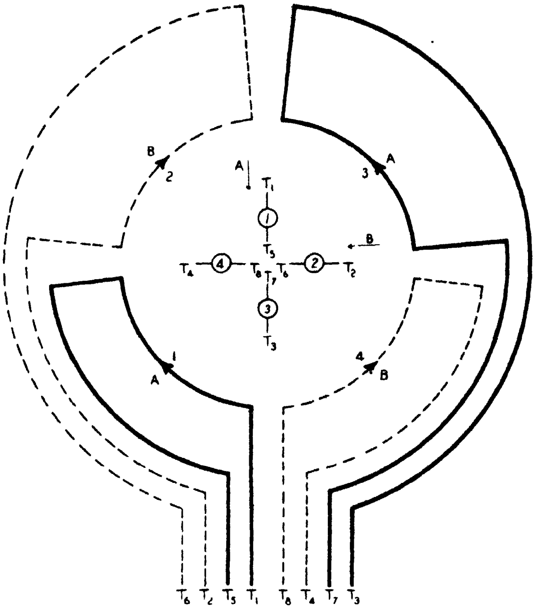


Fig. 3-12. 2-pole, 2-phase, series or 2-parallel connection diagram with 8 leads

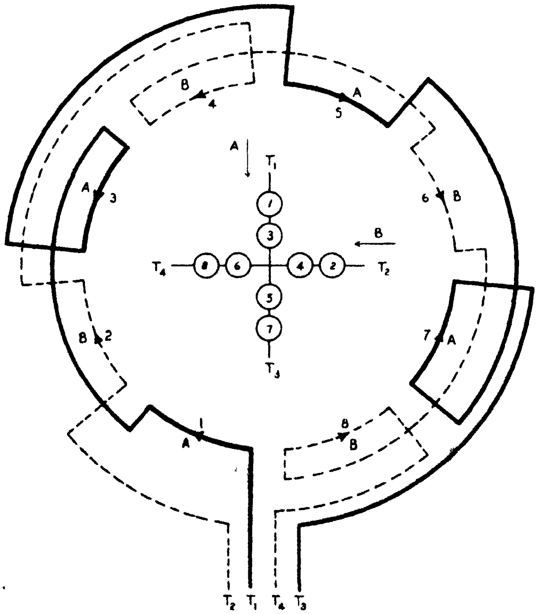


Fig. 3-13. 4-pole, 2-phase, series connection diagram T-T

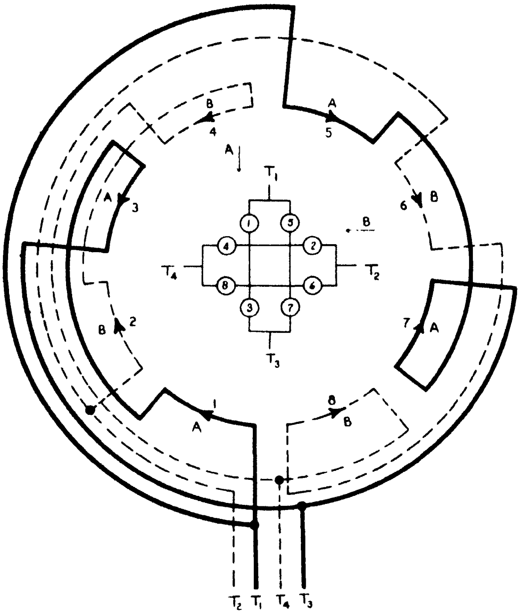


Fig. 3-14. 4-pole, 2-phase, 2-parallel connection diagram

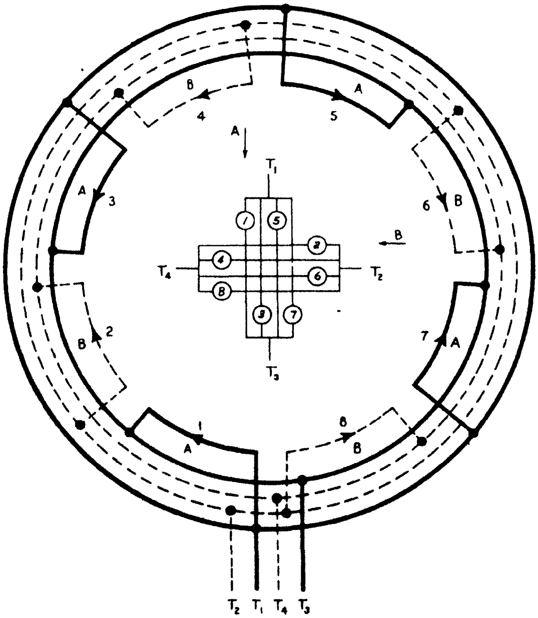


Fig. 3-15. 4-pole, 2-phase, 4-parallel connection diagram

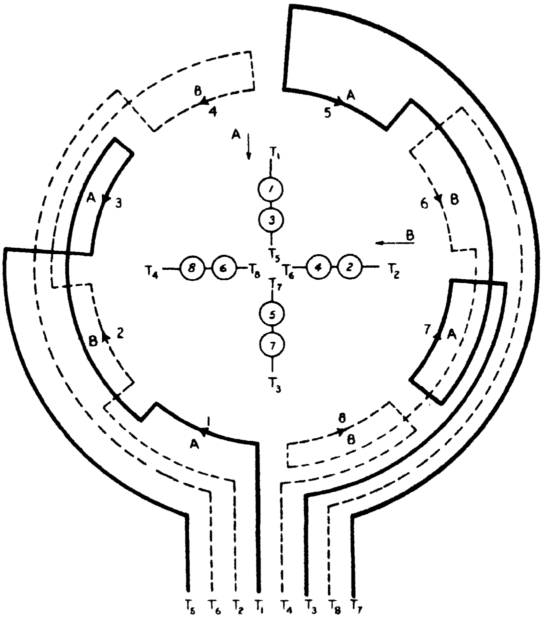


Fig. 3-16. 4-pole, 2-phase, series or 2-parallel connection diagram with 8 leads

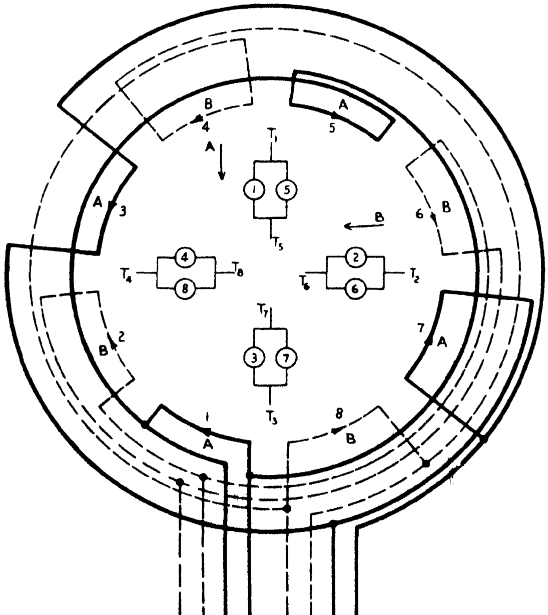


Fig. 3-17. 4-pole, 2-phase, 2- or 4-parallel connection diagram with 8 leads

TABLE 3-7
4-POLE 2-PHASE T-T CONNECTION TABLE

(Reference Connection Diagrams Figs. 3-13, 3-14, 3-15)

Phase	Connections						Leads	
A	Series	S_1	$F_1 \rightarrow F_3$	$S_3 \rightarrow S_5$	$F_5 \rightarrow F_7$	S_7	$T_1 \rightarrow S_1$	$T_3 \rightarrow S_7$
	2-parallel	S_1	$F_1 \rightarrow F_3$	$S_3 \parallel S_5$	$F_5 \rightarrow F_7$	S_7	$T_1 \rightarrow S_1 \rightarrow S_5$	$T_3 \rightarrow S_3 \rightarrow S_7$
	4-parallel	S_1	$F_1 \parallel F_3$	$S_3 \parallel S_5$	$F_5 \parallel F_7$	S_7	$T_1 \rightarrow S_1 \rightarrow F_3 \rightarrow S_5 \rightarrow F_7$	$T_3 \rightarrow F_1 \rightarrow S_3 \rightarrow F_5 \rightarrow S_7$
B	Series	S_2	$F_2 \rightarrow F_4$	$S_4 \rightarrow S_6$	$F_6 \rightarrow F_8$	S_8	$T_2 \rightarrow S_2$	$T_4 \rightarrow S_8$
	2-parallel	S_2	$F_2 \rightarrow F_4$	$S_4 \parallel S_6$	$F_6 \rightarrow F_8$	S_8	$T_2 \rightarrow S_2 \rightarrow S_6$	$T_4 \rightarrow S_4 \rightarrow S_8$
	4-parallel	S_2	$F_2 \parallel F_4$	$S_4 \parallel S_6$	$F_6 \parallel F_8$	S_8	$T_2 \rightarrow S_2 \rightarrow F_4 \rightarrow S_6 \rightarrow F_8$	$T_4 \rightarrow F_2 \rightarrow S_4 \rightarrow F_6 \rightarrow S_8$

S = start of a group.
F = finish of a group.
→ connected to start or finish of a group.
‖ spot for change with respect to series connection.
T-T = Top-to-top or short-jumper connection.

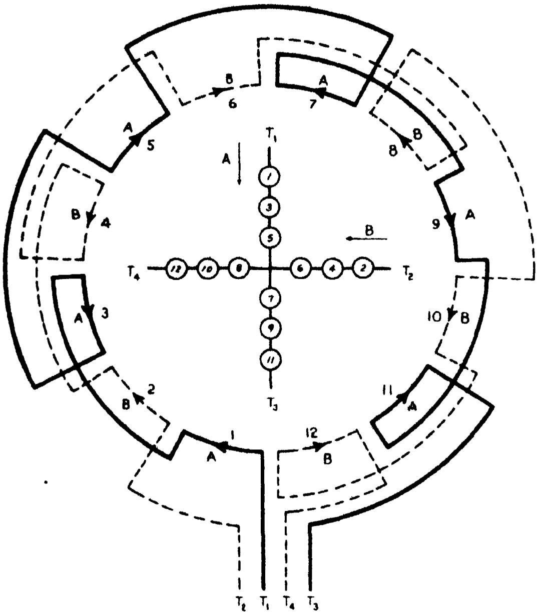


Fig. 3-18. 6-pole, 2-phase, series connection diagram T-T

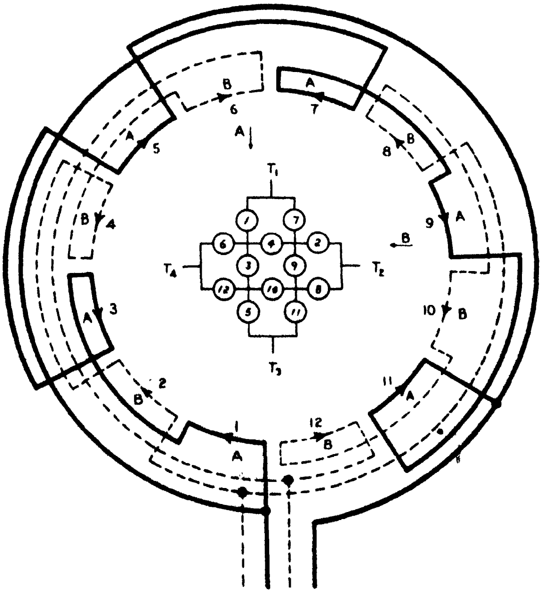


Fig. 3-19. 6-pole, 2-phase, 2-parallel connection diagram

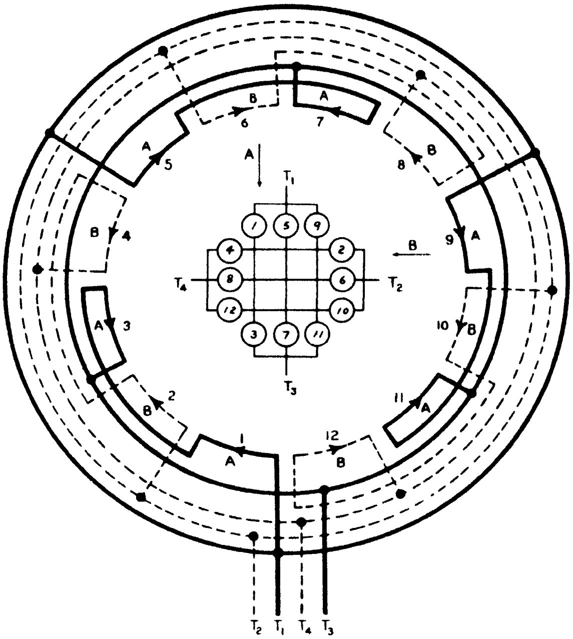


Fig. 3-20. 6-pole, 2-phase, 3-parallel connection diagram

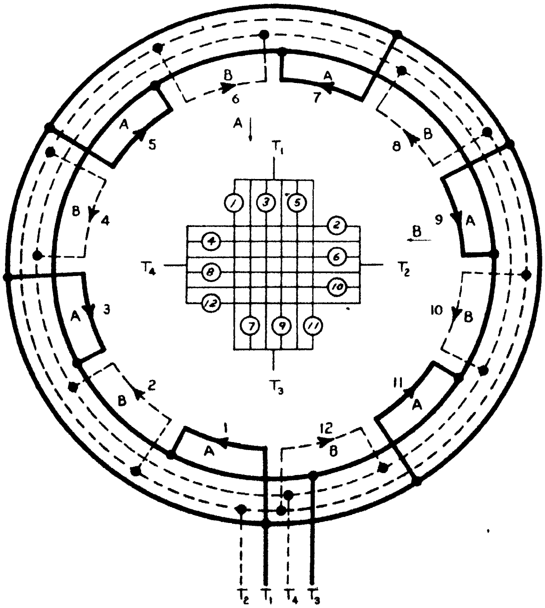


Fig. 3-21. 6-pole, 2-phase, 6-parallel connection diagram

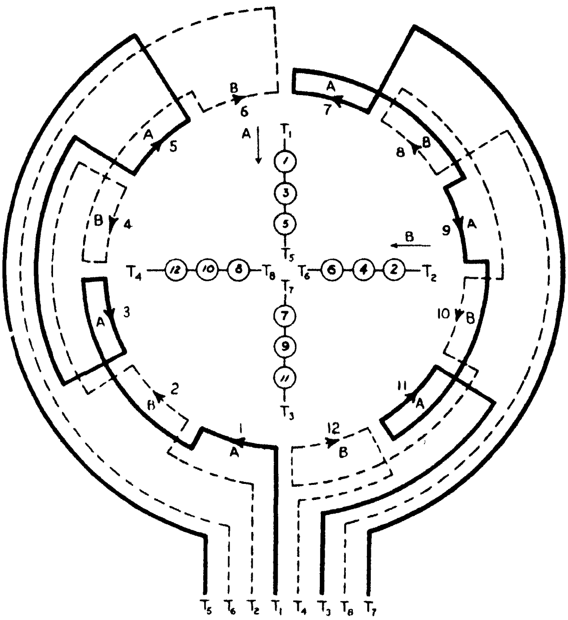


Fig. 3-22. 6-pole, 2-phase, series or 2-parallel connection diagram with 8 leads

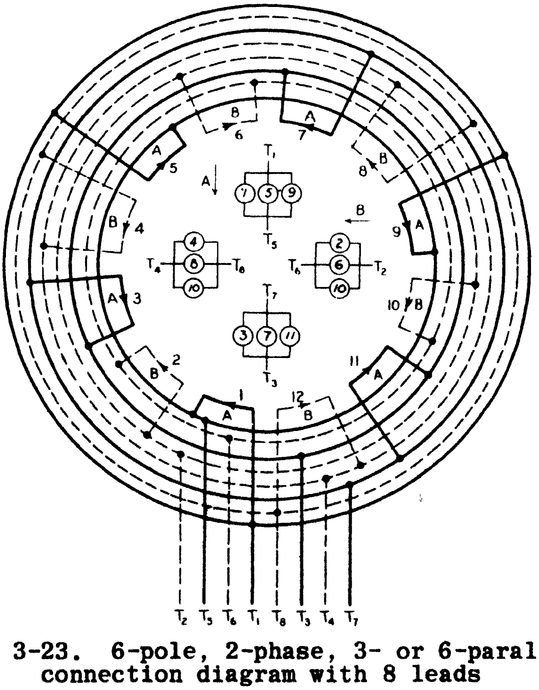


Fig. 3-23. 6-pole, 2-phase, 3- or 6-parallel connection diagram with 8 leads

TABLE 3-8

6-POLE 2-PHASE T-T CONNECTION TABLE

(Reference Connection Diagrams Figs. 3-18, 3-19, 3-20, 3-21)

Phase	Connections		Leads
A	Series	$S_1 \quad F_1 \to F_3 \quad S_3 \to S_5 \quad F_5 \to F_7 \quad S_7 \to S_9 \quad F_9 \to F_{11} \quad S_{11}$	$T_1 \to S_1$ $T_3 \to S_{11}$
	2-parallel	$S_1 \quad F_1 \to F_3 \quad S_3 \to S_5 \quad F_5 \parallel F_7 \quad S_7 \to S_9 \quad F_9 \to F_{11} \quad S_{11}$	$T_1 \to S_1 \to F_7$ $T_3 \to F_5 \to S_{11}$
	3-parallel	$S_1 \quad F_1 \to F_3 \quad S_3 \parallel S_5 \quad F_5 \to F_7 \quad S_7 \parallel S_9 \quad F_9 \to F_{11} \quad S_{11}$	$T_1 \to S_1 \to S_5 \to S_9$ $T_3 \to S_3 \to S_7 \to S_{11}$
	6-parallel	$S_1 \quad F_1 \parallel F_3 \quad S_3 \parallel S_5 \quad F_5 \parallel F_7 \quad S_7 \parallel S_9 \quad F_9 \parallel F_{11} \quad S_{11}$	$T_1 \to S_1 \to F_3 \to S_5 \to F_7 \to S_9 \to F_{11}$ $T_3 \to F_1 \to S_3 \to F_5 \to S_7 \to F_9 \to S_{11}$
B	Series	$S_2 \quad F_2 \to F_4 \quad S_4 \to S_6 \quad F_6 \to F_8 \quad S_8 \to S_{10} \quad F_{10} \to F_{12} \quad S_{12}$	$T_2 \to S_2$ $T_4 \to S_{12}$
	2-parallel	$S_2 \quad F_2 \to F_4 \quad S_4 \to S_6 \quad F_6 \parallel F_8 \quad S_8 \to S_{10} \quad F_{10} \to F_{12} \quad S_{12}$	$T_2 \to S_2 \to F_8$ $T_4 \to F_6 \to S_{12}$
	3-parallel	$S_2 \quad F_2 \to F_4 \quad S_4 \parallel S_6 \quad F_6 \to F_8 \quad S_8 \parallel S_{10} \quad F_{10} \to F_{12} \quad S_{12}$	$T_2 \to S_2 \to S_6 \to S_{10}$ $T_4 \to S_4 \to S_8 \to S_{12}$
	6-parallel	$S_2 \quad F_2 \parallel F_4 \quad S_4 \parallel S_6 \quad F_6 \parallel F_8 \quad S_8 \parallel S_{10} \quad F_{10} \parallel F_{12} \quad S_{12}$	$T_2 \to S_2 \to F_4 \to S_6 \to F_8 \to S_{10} \to F_{12}$ $T_4 \to F_2 \to S_4 \to F_6 \to S_8 \to F_{10} \to S_{12}$

S = start of a group.
F = finish of a group.
→ connected to start or finish of a group.
‖ spot for change with respect to series connection.
T-T = Top-to-top or short-jumper connection.

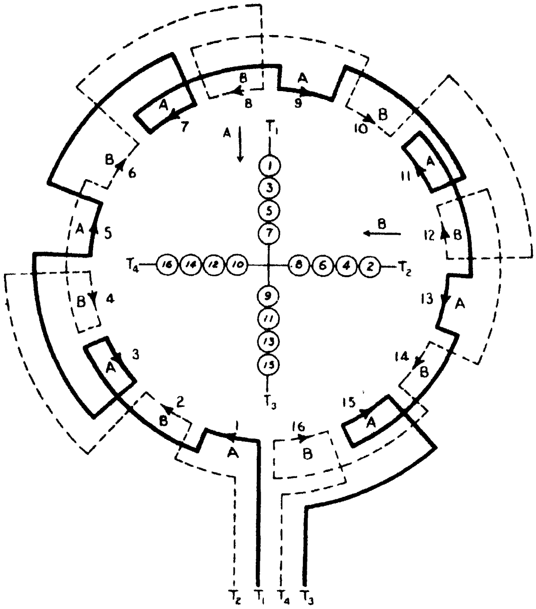


Fig. 3-24. 8-pole, 2-phase,series connection diagram T-T

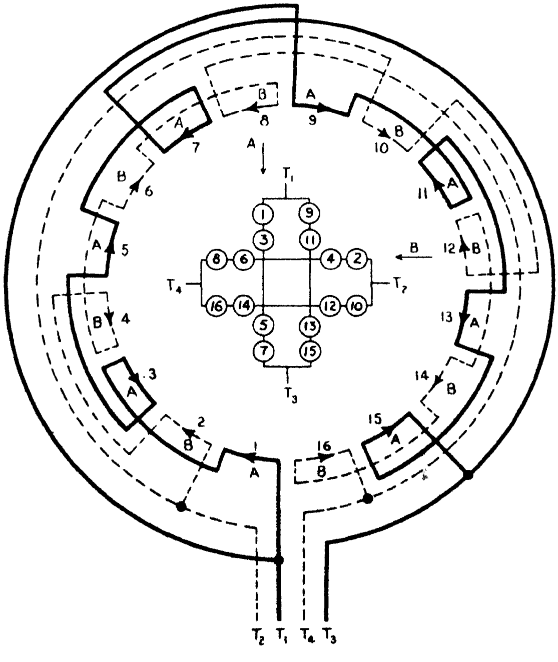


Fig. 3-25. 8-pole, 2-phase, 2-parallel connection diagram

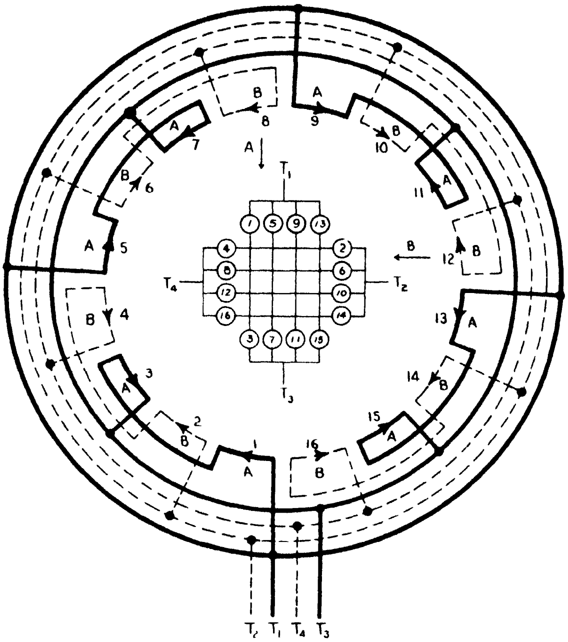


Fig. 3-26. 8-pole, 2-phase, 4-parallel connection diagram

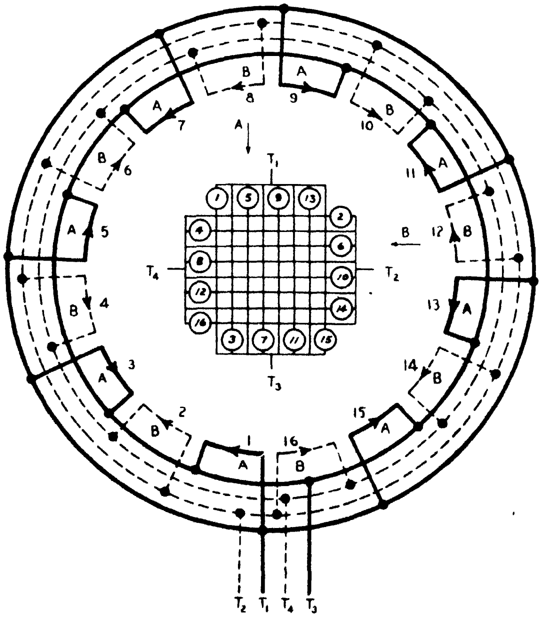


Fig. 3-27. 8-pole, 2-phase, 8-parallel connection diagram

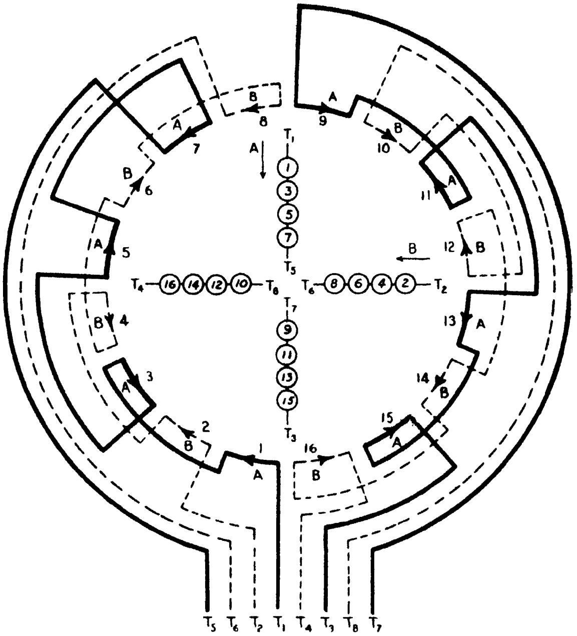


Fig. 3-28. 8-pole, 2-phase, series or 2-parallel connection diagram with 8 leads

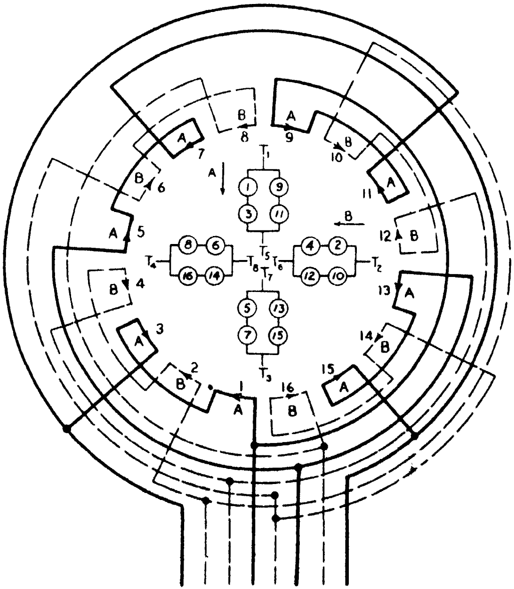


Fig. 3-29. 8-pole, 2-phase, 2- or 4-parallel connection diagram with 8 leads

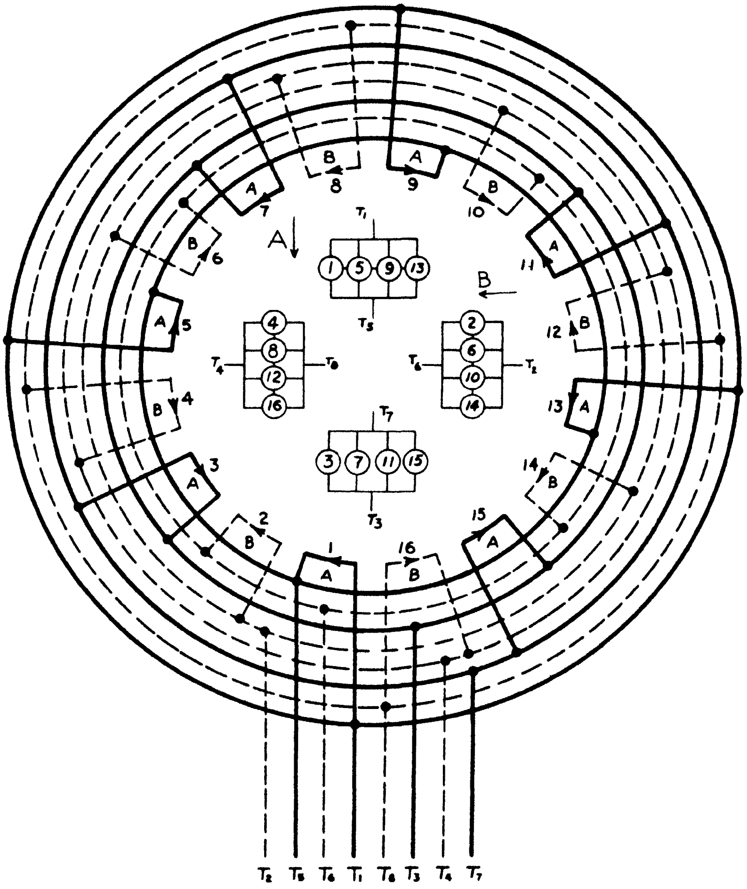


Fig. 3-30. 8-pole, 2-phase, 4- or 8-parallel connection diagram with 8 leads

TABLE 3-9
8-POLE 2-PHASE T-T CONNECTION TABLE
(Reference Connection Diagrams Figs. 3-24, 3-25, 3-26, 3-27)

Phase	Connections		Leads
A	Series	$S_1\ \ F_1 \to F_3\ \ S_3 \to S_5\ \ F_5 \to F_7\ \ S_7 \to S_9\ \ F_9 \to F_{11}\ \ S_{11} \to S_{13}\ \ F_{13} \to F_{15}\ \ S_{15}$	$T_1 \to S_1$ $T_3 \to S_{15}$
	2-parallel	$S_1\ \ F_1 \to F_3\ \ S_3 \to S_5\ \ F_5 \to F_7\ \ S_7 \parallel S_9\ \ F_9 \to F_{11}\ \ S_{11} \to S_{13}\ \ F_{13} \to F_{15}\ \ S_{15}$	$T_1 \to S_1 \to S_9$ $T_3 \to S_7 \to S_{15}$
	4-parallel	$S_1\ \ F_1 \to F_3\ \ S_3 \parallel S_5\ \ F_5 \to F_7\ \ S_7 \parallel S_9\ \ F_9 \to F_{11}\ \ S_{11} \parallel S_{13}\ \ F_{13} \to F_{15}\ \ S_{15}$	$T_1 \to S_1 \to S_5 \to S_9 \to S_{13}$ $T_3 \to S_3 \to S_7 \to S_{11} \to S_{15}$
	8-parallel	$S_1\ \ F_1 \parallel F_3\ \ S_3 \parallel S_5\ \ F_5 \parallel F_7\ \ S_7 \parallel S_9\ \ F_9 \parallel F_{11}\ \ S_{11} \parallel S_{13}\ \ F_{13} \parallel F_{15}\ \ S_{15}$	$T_1 \to S_1 \to F_3 \to S_5 \to F_7 \to S_9 \to F_{11} \to S_{13} \to F_{15}$ $T_3 \to F_1 \to S_3 \to F_5 \to S_7 \to F_9 \to S_{11} \to F_{13} \to S_{15}$
B	Series	$S_2\ \ F_2 \to F_4\ \ S_4 \to S_6\ \ F_6 \to F_8\ \ S_8 \to S_{10}\ \ F_{10} \to F_{12}\ \ S_{12} \to S_{14}\ \ F_{14} \to F_{16}\ \ S_{16}$	$T_2 \to S_2$ $T_4 \to S_{16}$
	2-parallel	$S_2\ \ F_2 \to F_4\ \ S_4 \to S_6\ \ F_6 \to F_8\ \ S_8 \parallel S_{10}\ \ F_{10} \to F_{12}\ \ S_{12} \to S_{14}\ \ F_{14} \to F_{16}\ \ S_{16}$	$T_2 \to S_2 \to S_{10}$ $T_4 \to S_8 \to S_{16}$
	4-parallel	$S_2\ \ F_2 \to F_4\ \ S_4 \parallel S_6\ \ F_6 \to F_8\ \ S_8 \parallel S_{10}\ \ F_{10} \to F_{12}\ \ S_{12} \parallel S_{14}\ \ F_{14} \to F_{16}\ \ S_{16}$	$T_2 \to S_2 \to S_6 \to S_{10} \to S_{14}$ $T_4 \to S_4 \to S_8 \to S_{12} \to S_{16}$
	8-parallel	$S_2\ \ F_2 \parallel F_4\ \ S_4 \parallel S_6\ \ F_6 \parallel F_8\ \ S_8 \parallel S_{10}\ \ F_{10} \parallel F_{12}\ \ S_{12} \parallel S_{14}\ \ F_{14} \parallel F_{16}\ \ S_{16}$	$T_2 \to S_2 \to F_4 \to S_6 \to F_8 \to S_{10} \to F_{12} \to S_{14} \to F_{16}$ $T_4 \to F_2 \to S_4 \to F_6 \to S_8 \to F_{10} \to S_{12} \to F_{14} \to S_{16}$

S = start of a group.

F = finish of a group.

→ connected to start or finish of a group.

|| spot for change with respect to series connection.

T-T = Top-to-top or short-jumper connection.

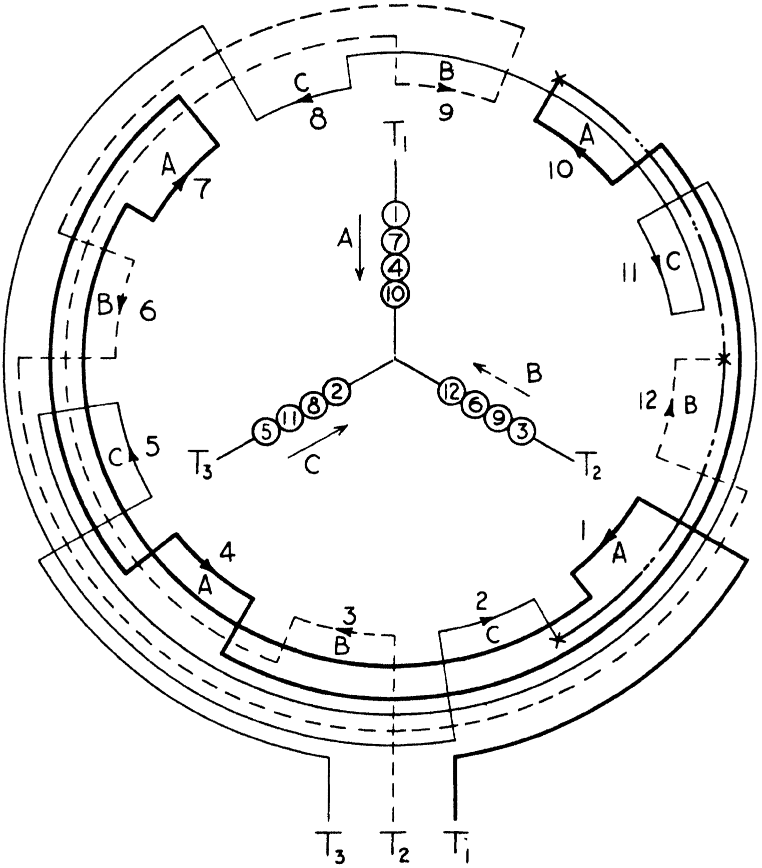


Fig. 3-31. 4-pole, 3-phase, series star connection diagram T-B

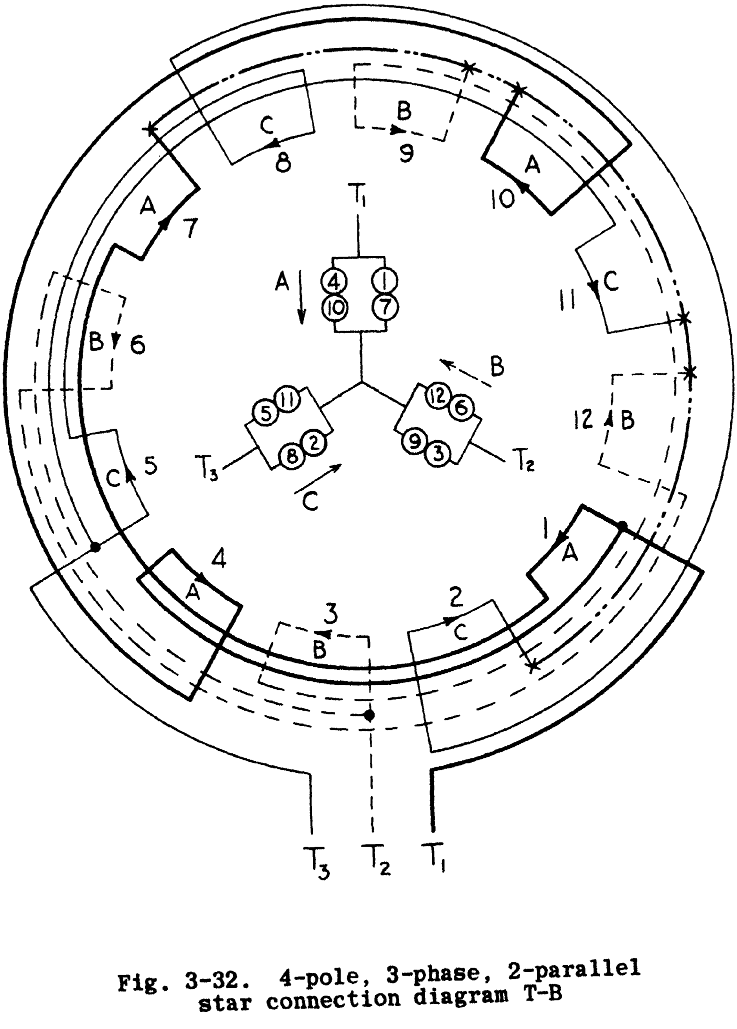


Fig. 3-32. 4-pole, 3-phase, 2-parallel star connection diagram T-B

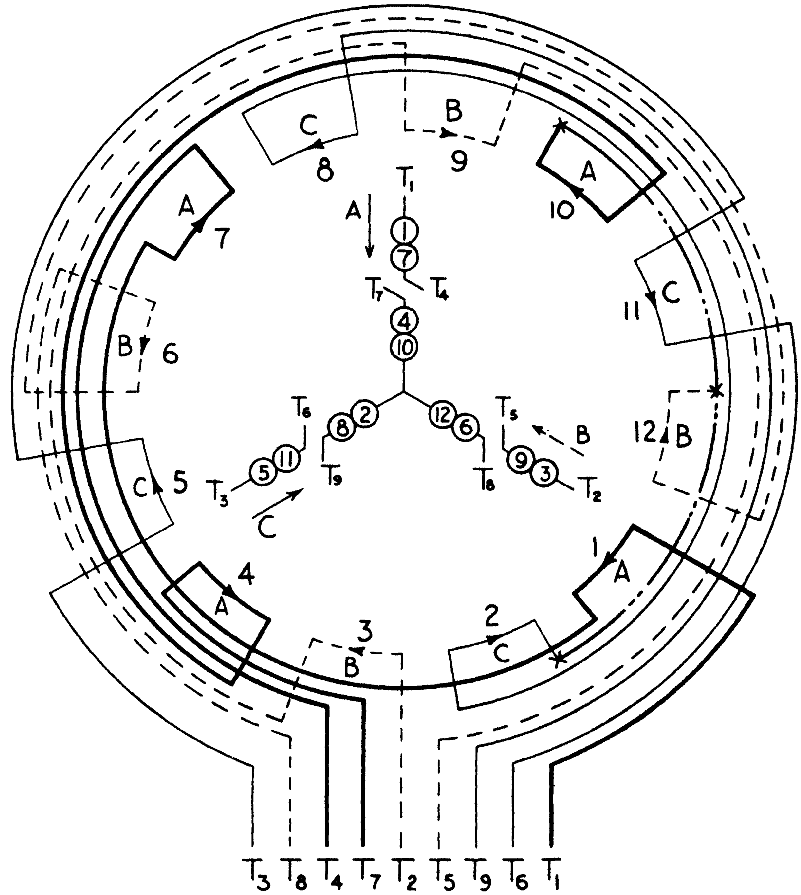


Fig. 3-33. 4-pole, 3-phase, series or 2-parallel star connection diagram with 9 leads T-B

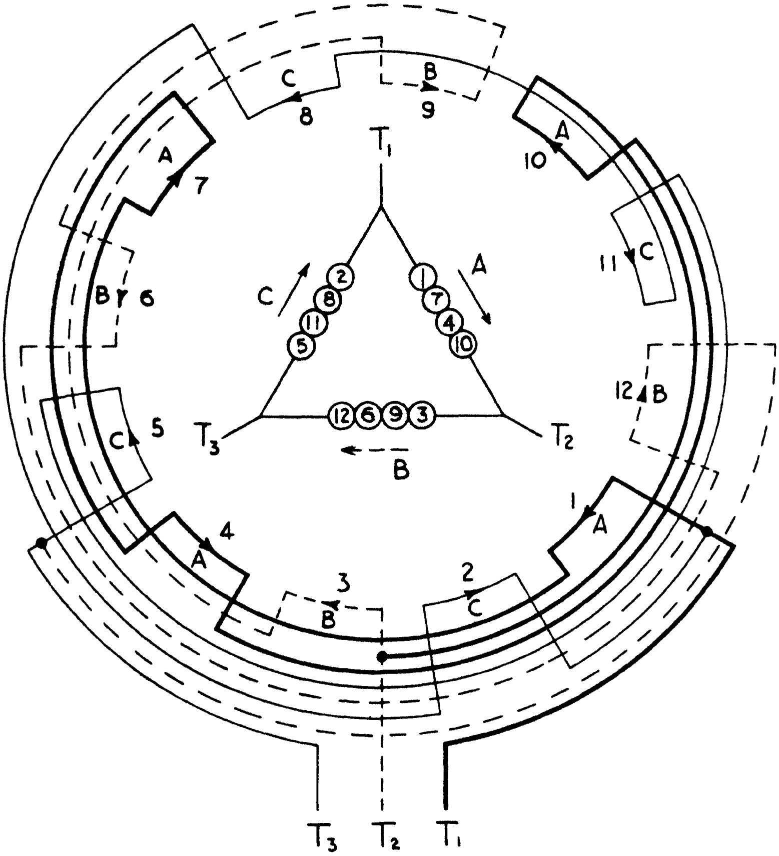


Fig. 3-34. 4-pole, 3-phase, series delta connection diagram T-B

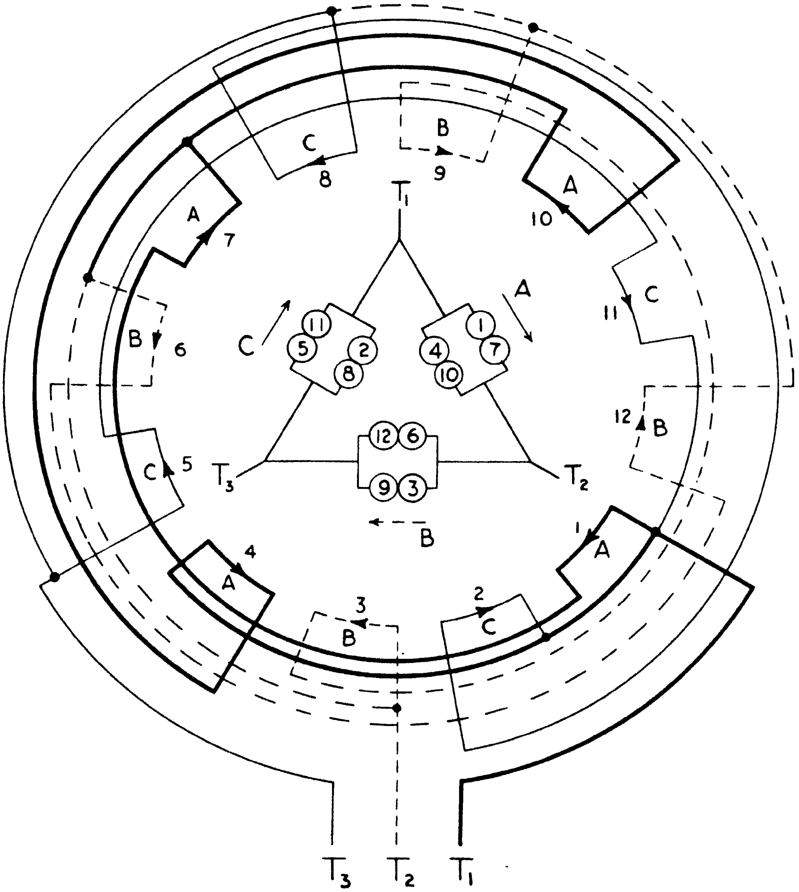


Fig. 3-35. 4-pole, 3-phase, 2-parallel delta connection diagram T-B

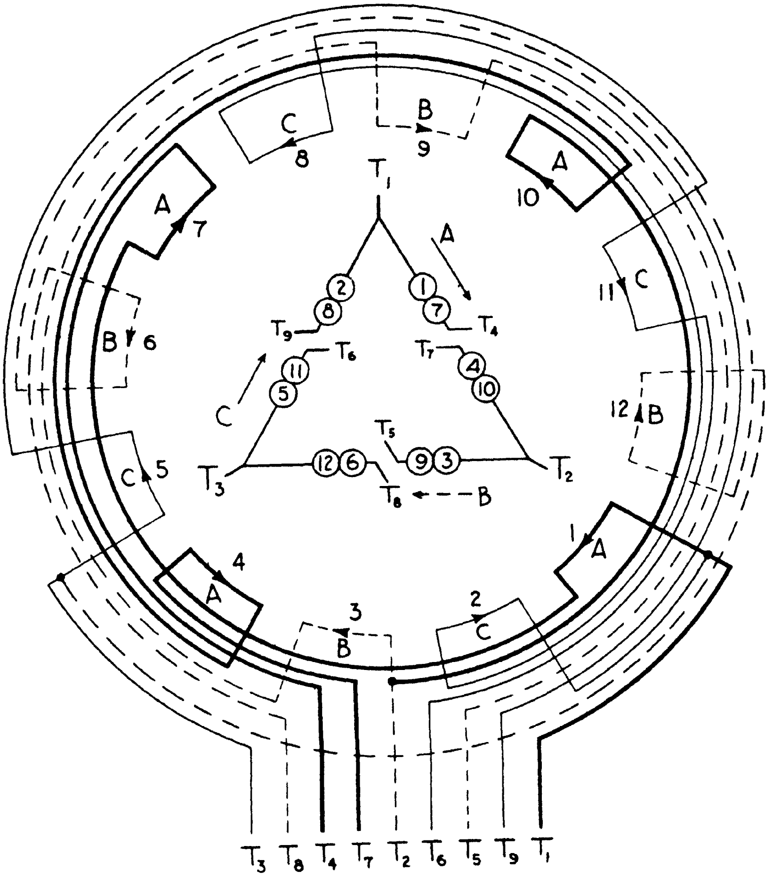


Fig. 3-36. 4-pole, 3-phase, series or 2-parallel delta connection diagram with 9 leads T-B

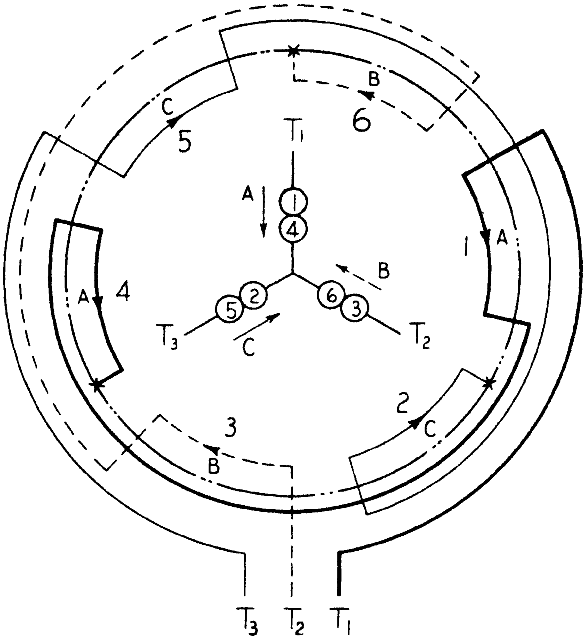


Fig. 3-37. 2-pole, 3-phase, series star connection diagram T-T

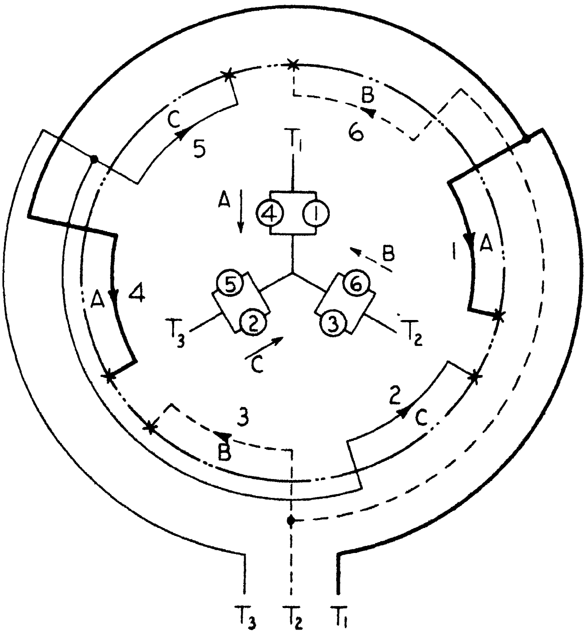


Fig. 3-38. 2-pole, 3-phase, 2-parallel star connection diagram

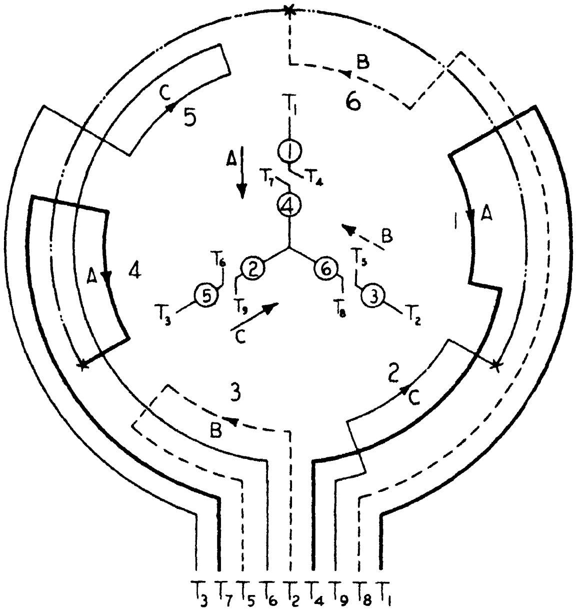


Fig. 3-39. 2-pole, 3-phase, series or 2-parallel star connection diagram with 9 leads

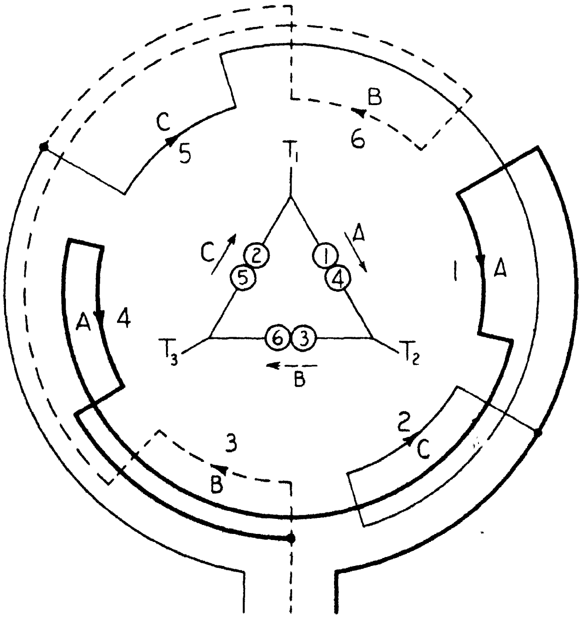


Fig. 3-40. 2-pole, 3-phase, series delta connection diagram T-T

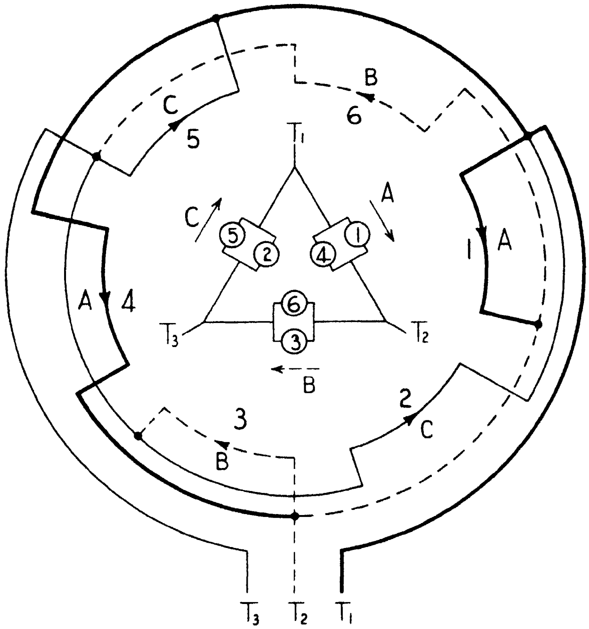


Fig. 3-41. 2-pole, 3-phase, 2-parallel delta connection diagram

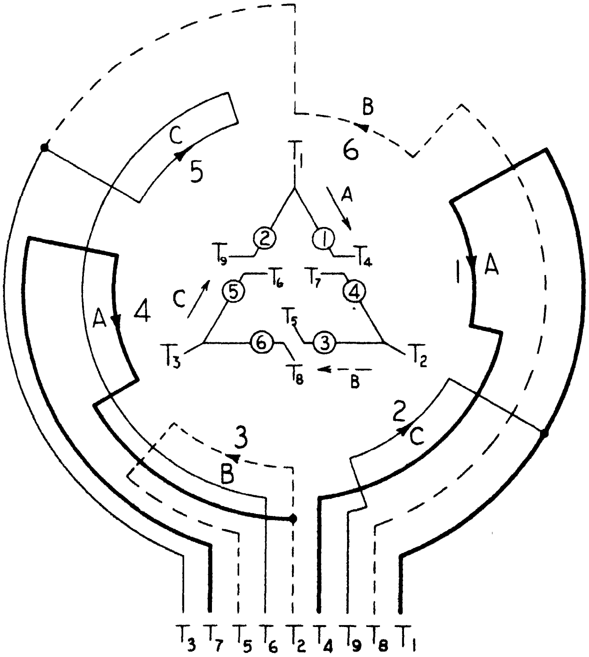


Fig. 3-42. 2-pole, 3-phase, series or 2-parallel delta connection diagram with 9 leads

TABLE 3-10

2-POLE 3-PHASE T-T CONNECTION TABLE

(Reference Connection Diagrams Figs. 3-37, 3-38, 3-40, 3-41)

Phase	Connections		Leads	
A	Series	S1 F1→F4 S4	T_1 → S1	T_4 → S4
	2-parallel	S1 F1‖F4 S4	T_1 → S1→F4	T_4 → F1→S4
B	Series	S3 F3→F6 S6	T_2 → S3	T_5 → S6
	2-parallel	S3 F3‖F6 S6	T_2 → S3→F6	T_5 → F3→S6
C	Series	S5 F5→F2 S2	T_3 → S5	T_6 → S2
	2-parallel	S5 F5‖F2 S2	T_3 → S5→F2	T_6 → F5→S2

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Δ Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

T-T = Top-to-top or bottom-to-bottom or short-jumper connection.

→ = connected to start or finish of a group.

‖ = spot for change with respect to series connection.

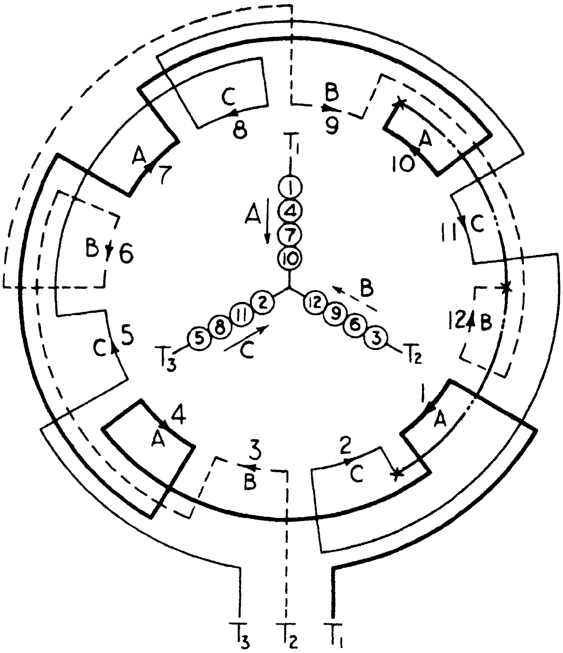


Fig. 3-43. 4-pole, 3-phase, series star connection diagram T-T

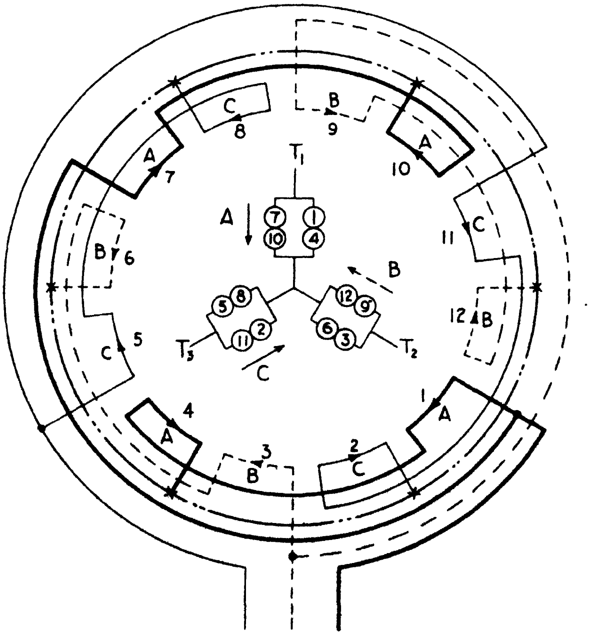


Fig. 3-44. 4-pole, 3-phase, 2-parallel star connection diagram T-T

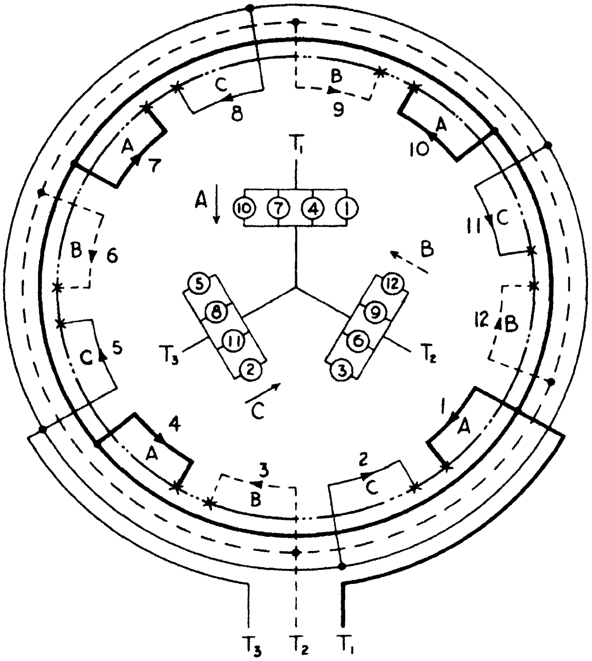


Fig. 3-45. 4-pole, 3-phase, 4-parallel star connection diagram T-T

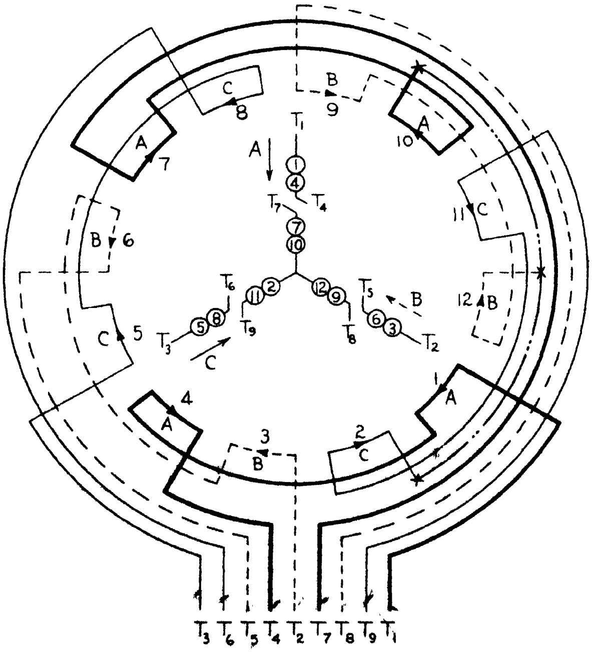


Fig. 3-46. 4-pole, 3-phase, series or 2-parallel star connection diagram with 9 leads

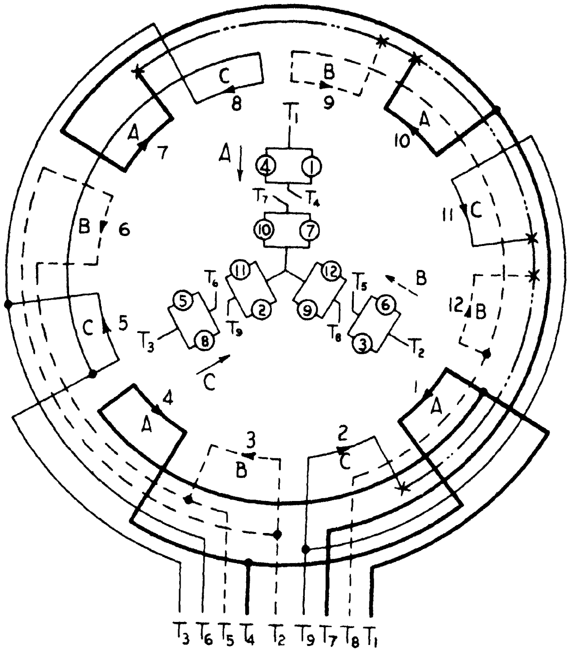


Fig. 3-47. 4-pole, 3-phase, 2- or 4-parallel star connection diagram with 9 leads

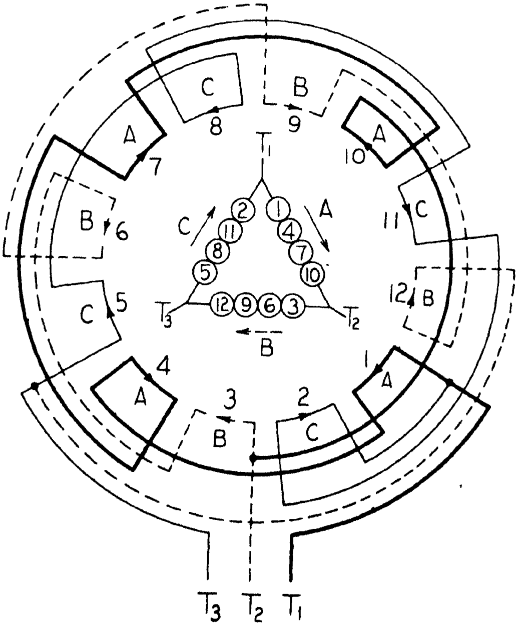


Fig. 3-48. 4-pole, 3-phase, series delta connection diagram T-T

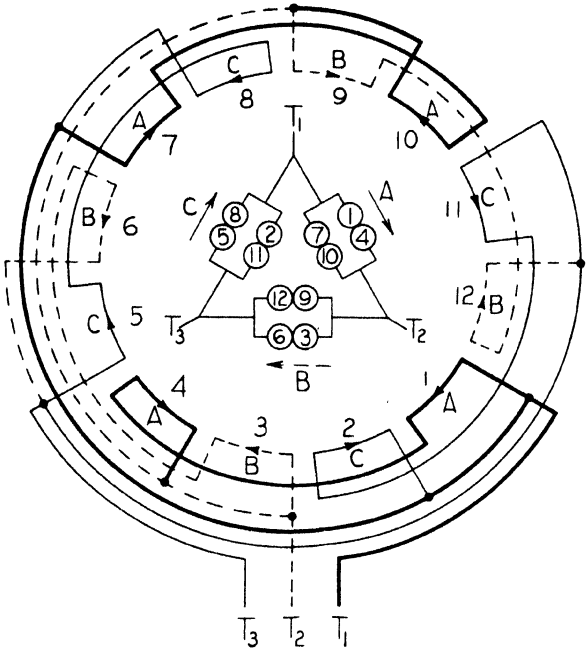


Fig. 3-49. 4-pole, 3-phase, 2-parallel delta connection diagram T-T

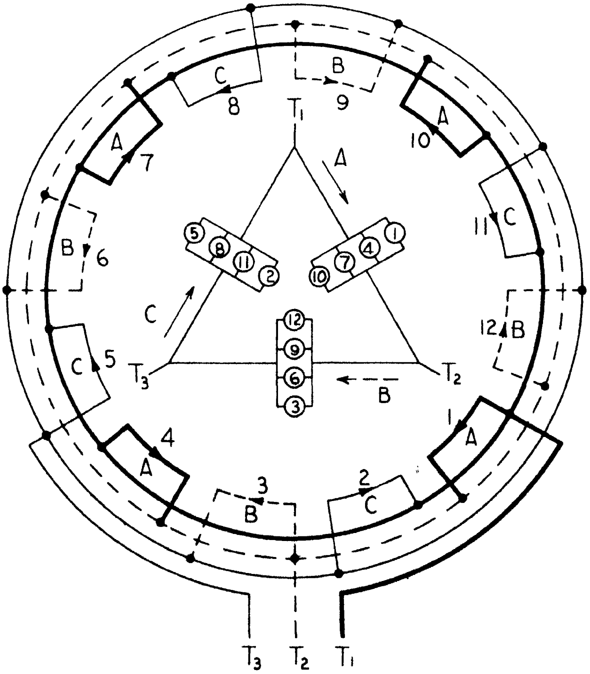


Fig. 3-50. 4-pole, 3-phase, 4-parallel delta connection diagram

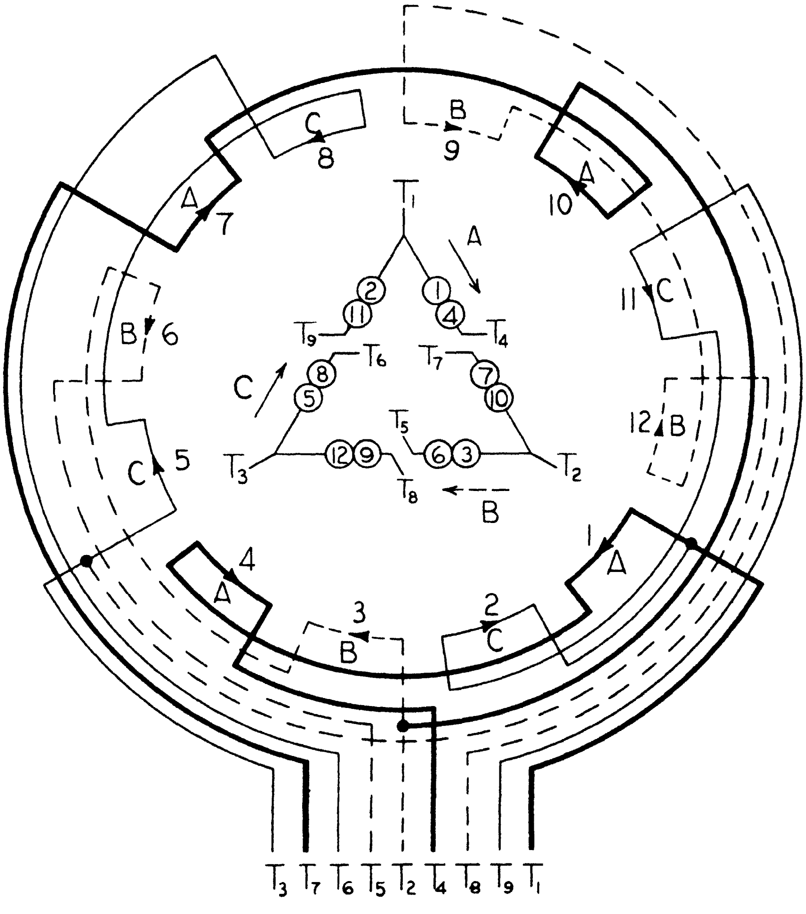


Fig. 3-51. 4-pole, 3-phase, series or 2-parallel delta connection diagram with 9 leads T-T

TABLE 3-11

4-POLE 3-PHASE T-T CONNECTION TABLE

(Reference Connection Diagrams Figs. 3-43, 3-44, 3-45, 3-48, 3-49, 3-50)

Phase	Connections		Leads	
A	Series	S1 F1→F4 S4→S7 F7→F10 S10	T_1 → S1	T_4 → S10
	2-parallel	S1 F1→F4 S4∥S7 F7→F10 S10	T_1 → S1→S7	T_4 → S4→S10
	4-parallel	S1 F1∥F4 S4∥S7 F7∥F10 S10	T_1 → S1→F4→S7→F10	T_4 → F1→S4→F7→S10
B	Series	S3 F3→F6 S6→S9 F9→F12 S12	T_2 → S3	T_5 → S12
	2-parallel	S3 F3→F6 S6∥S9 F9→F12 S12	T_2 → S3→S9	T_5 → S6→S12
	4-parallel	S3 F3∥F6 S6∥S9 F9∥F12 S12	T_2 → S3→F6→S9→F12	T_5 → F3→S6→F9→S12
C	Series	S5 F5→F8 S8→S11 F11→F2 S2	T_3 → S5	T_6 → S2
	2-parallel	S5 F5→F8 S8∥S11 F11→F2 S2	T_3 → S5→S11	T_6 → S8→S2
	4-parallel	S5 F5∥F8 S8∥S11 F11∥F2 S2	T_3 → S5→F8→S11→F2	T_6 → F5→S8→F11→S2

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Δ Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

→ = connected to start or finish of a group.

∥ = spot for change with respect to series connection

T-T = Top-to-top or bottom-to-bottom or short-jumper connection.

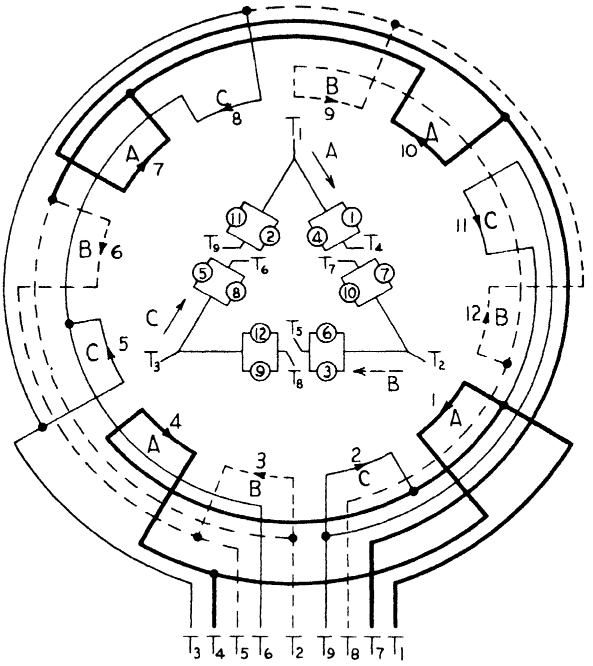


Fig. 3-52. 4-pole, 3-phase, 2- or 4-parallel delta connection diagram with 9 leads

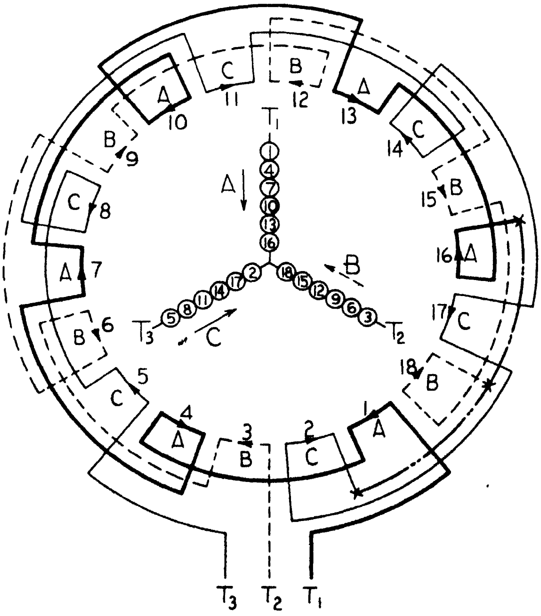


Fig. 3-53. 6-pole, 3-phase, series star connection diagram T-T

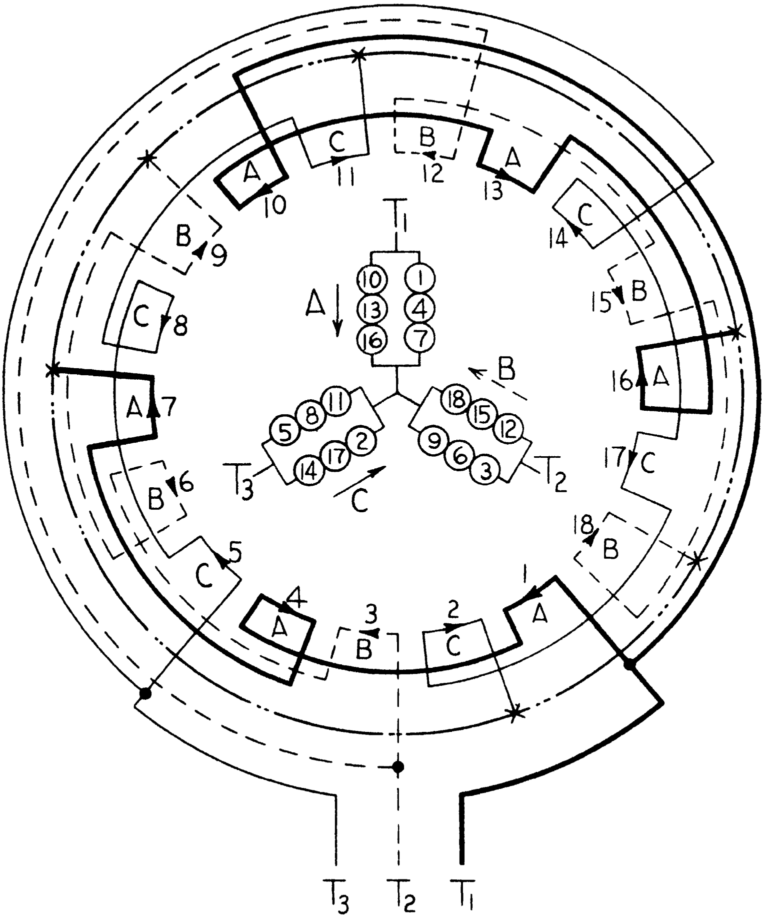


Fig. 3-54. 6-pole, 3-phase, 2-parallel star connection diagram T-T

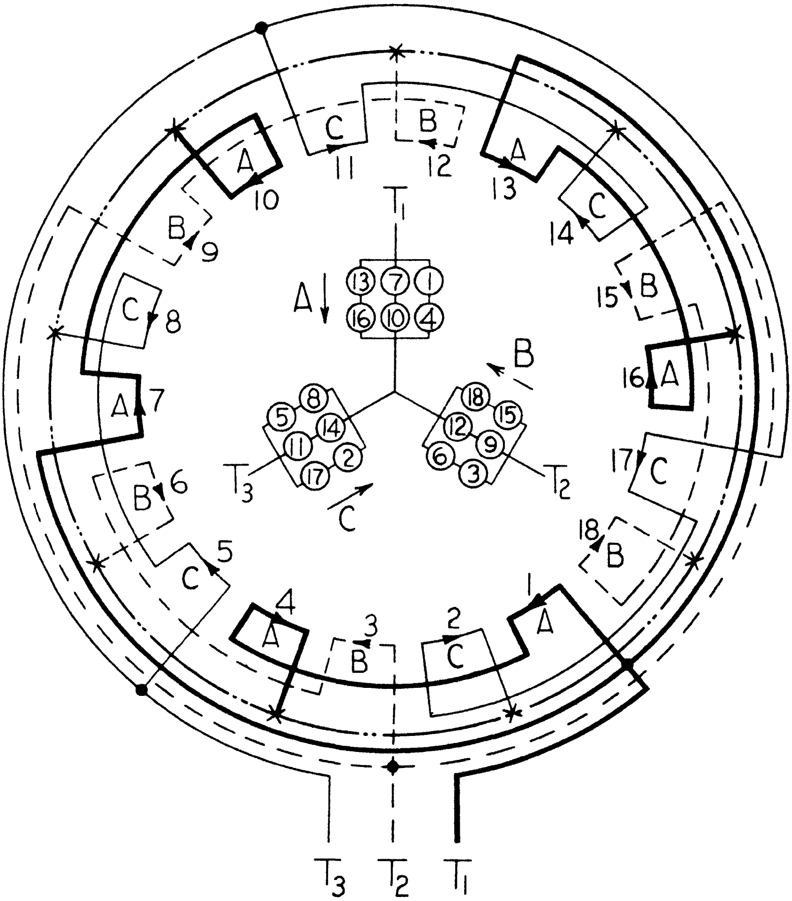


Fig. 3-55. 6-pole, 3-phase, 3-parallel star connection diagram T-T

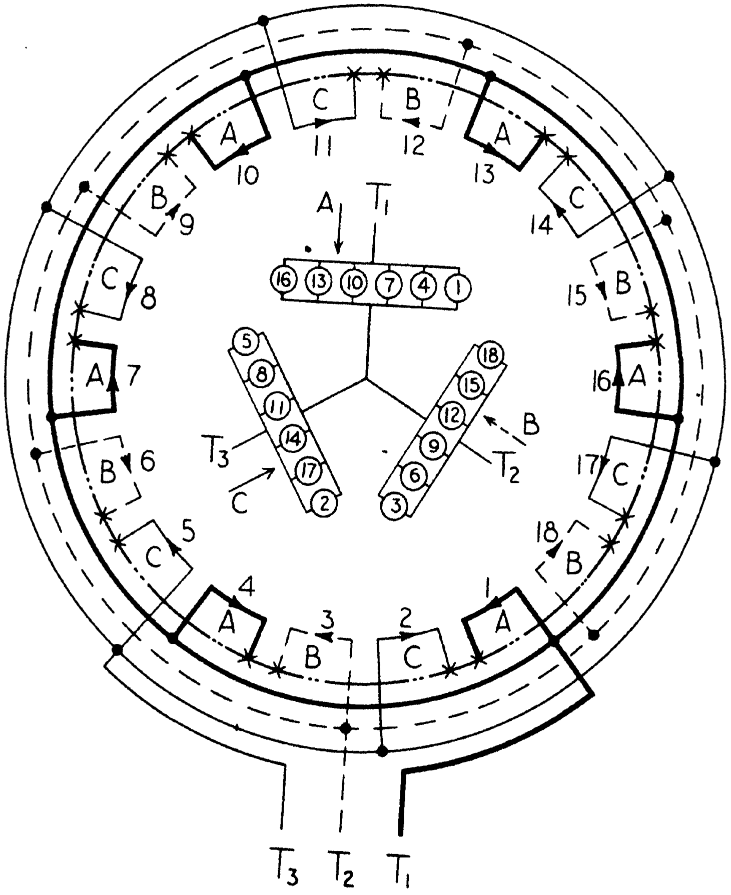


Fig. 3-56. 6-pole, 3-phase. 6-parallel star connection diagram

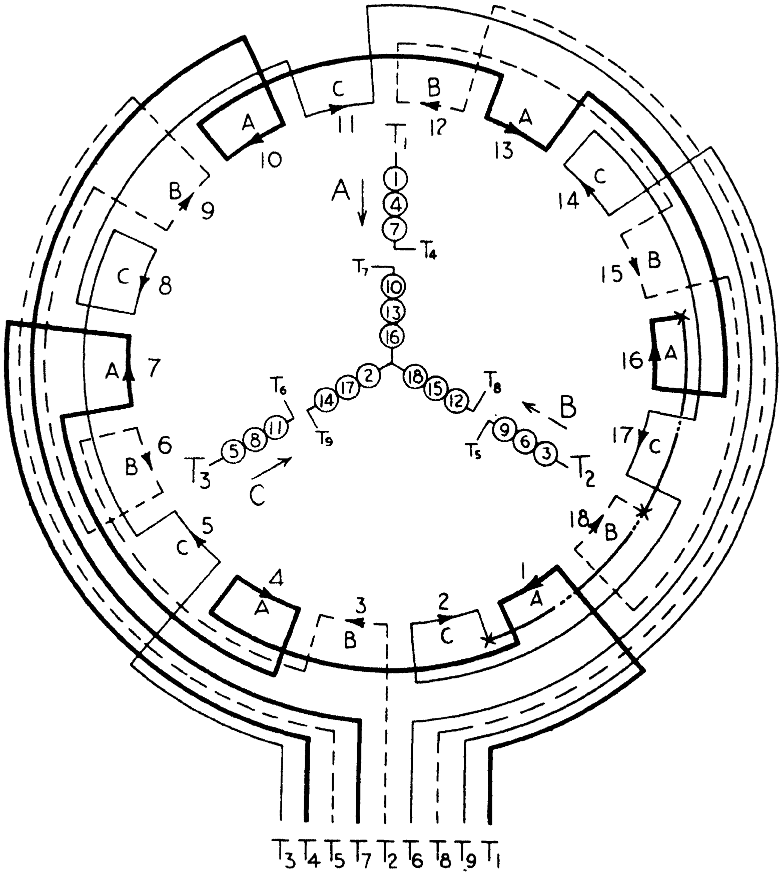


Fig. 3-57. 6-pole, 3-phase, series or 2-parallel star connection diagram with 9 leads T-T

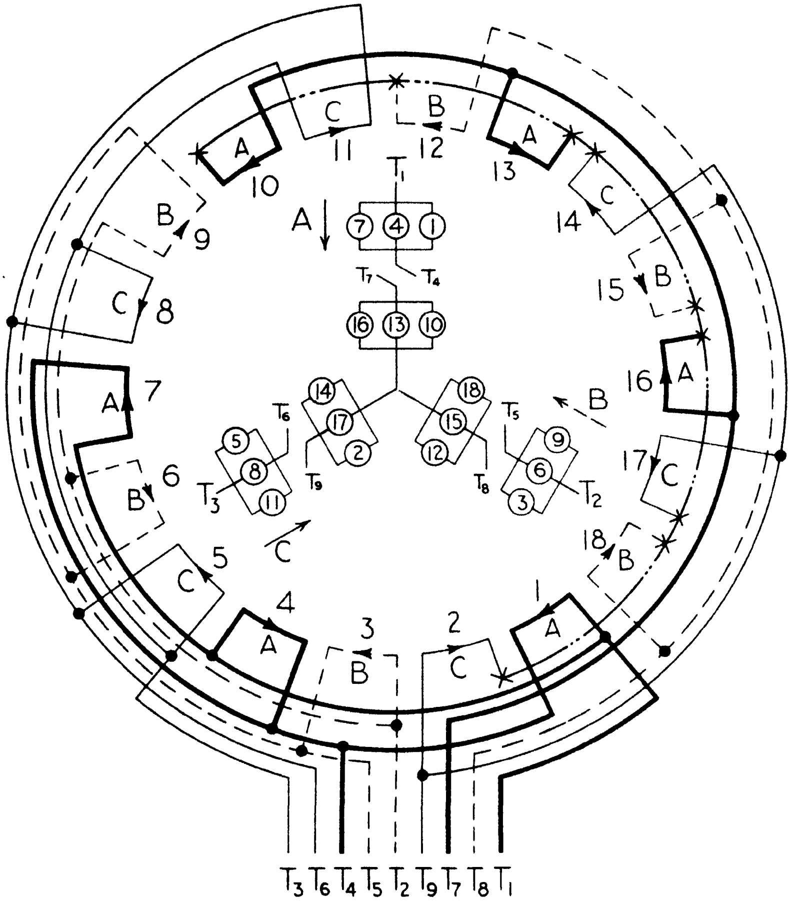


Fig. 3-58. 6-pole, 3-phase, 3- or 6-parallel star connection diagram with 9 leads

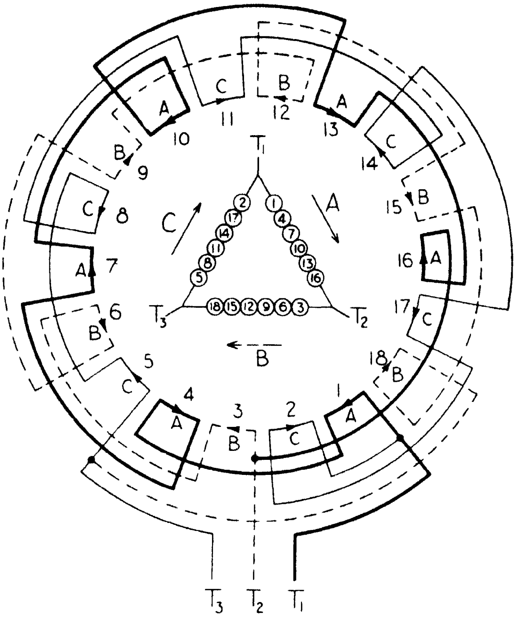


Fig. 3-59. 6-pole, 3-phase, series delta connection diagram T-T

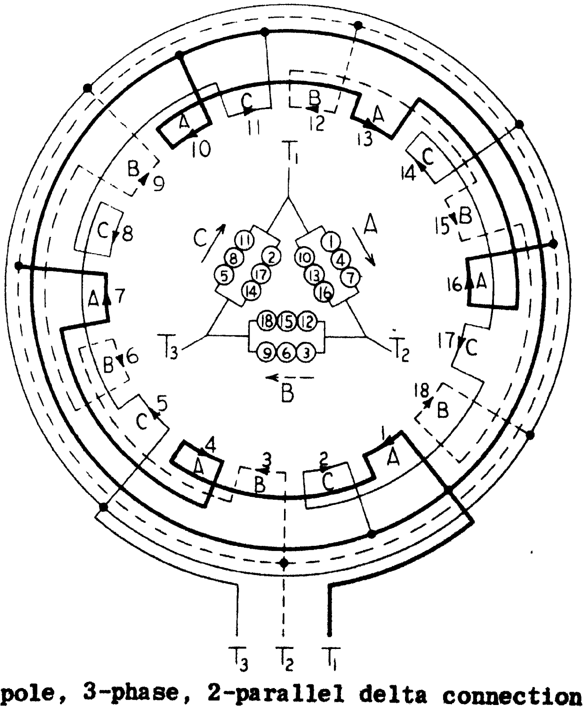


Fig. 3-60. 6-pole, 3-phase, 2-parallel delta connection diagram T-T

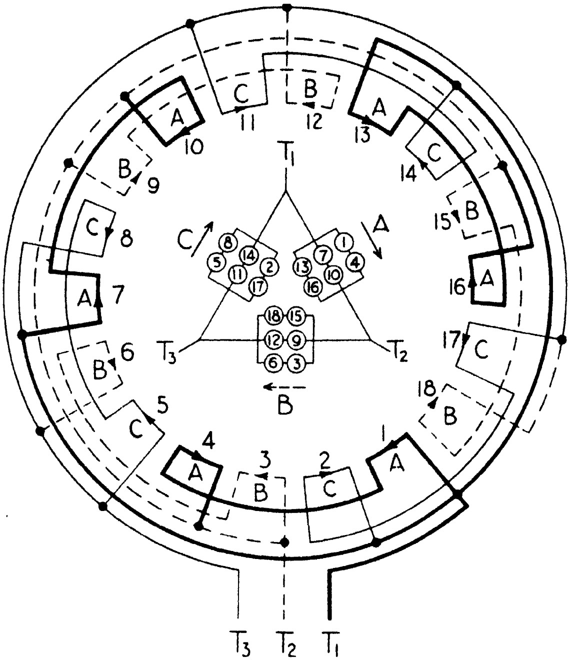


Fig. 3-61. 6-pole, 3-phase, 3-parallel delta connection diagram T-T

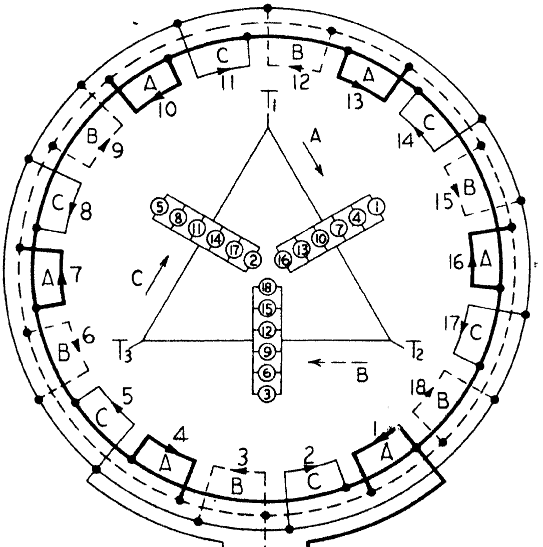


Fig. 3-62. 6-pole, 3-phase, 6-parallel delta connection diagram

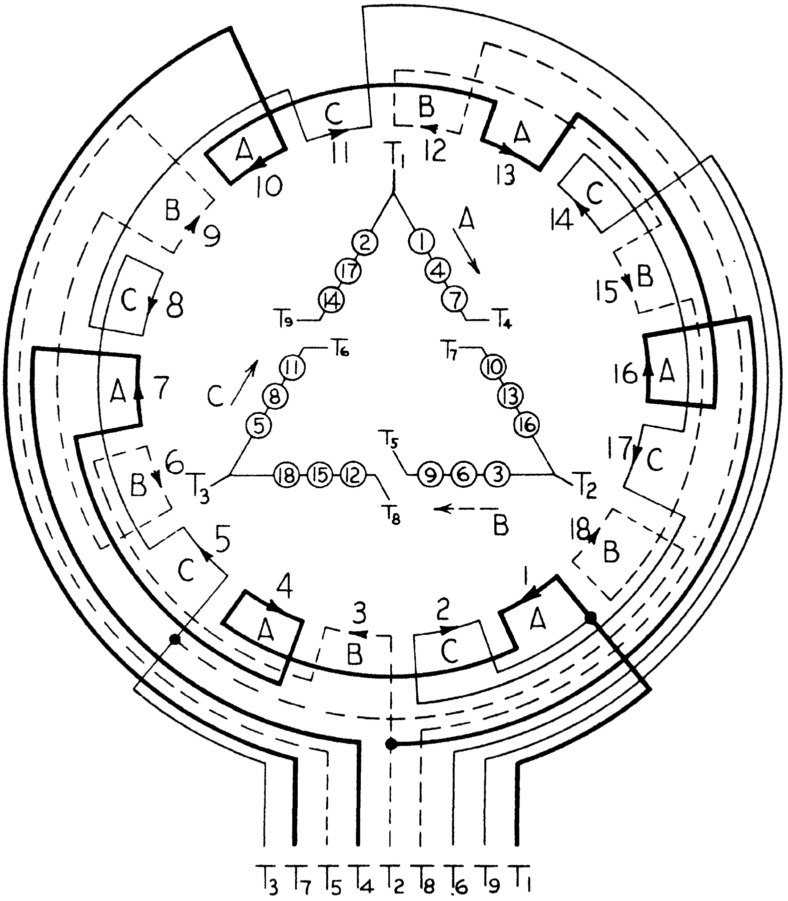


Fig. 3-63. 6-pole, 3-phase, series or 2-parallel delta connection diagram with 9 leads T-T

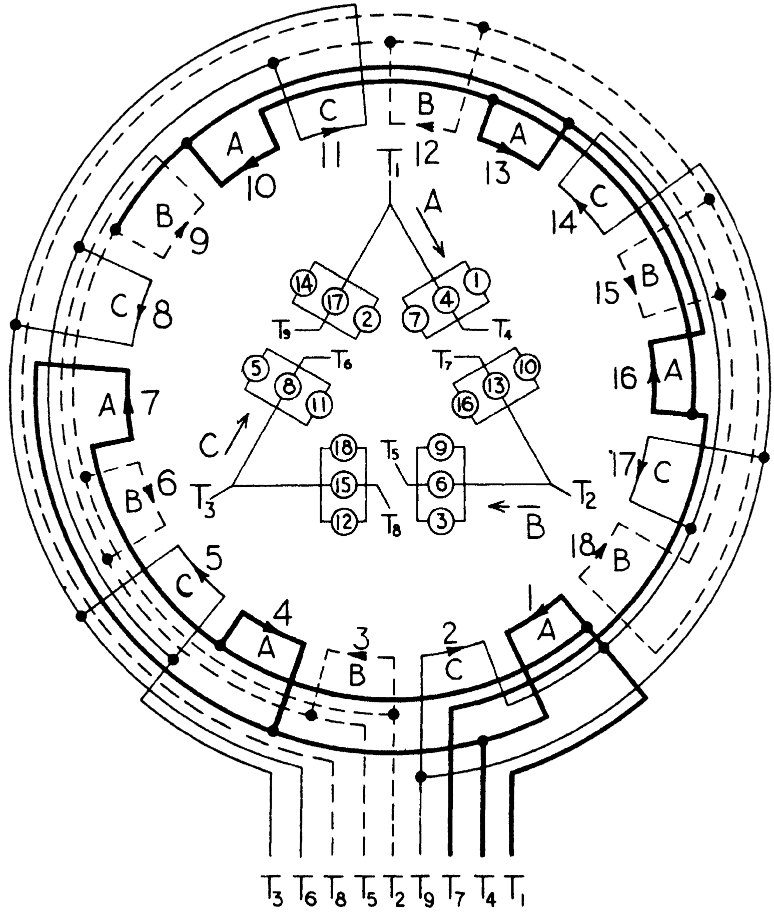


Fig. 3-64. 6-pole, 3-phase, 3- or 6-parallel delta connection diagram with 9 leads

TABLE 3-12

6-POLE 3-PHASE T-T CONNECTION TABLE

(Reference Connection Diagrams Figs. 3-53, 3-54, 3-55, 3-56, 3-59, 3-60, 3-61, 3-62)

Phase	Connections		Leads
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16	T_1 → S1 T_4 → S16
	2-parallel	S1 F1→F4 S4→S7 F7‖F10 S10→S13 F13→F16 S16	T_1 → S1→F10 T_4 → F7→S16
	3-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16	T_1 → S1→S7→S13 T_4 → S4→S10→S16
	6-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16	T_1 → S1→F4→S7→F10→S13→F16 T_4 → F1→S4→F7→S10→F13→S16
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18	T_2 → S3 T_5 → S18
	2-parallel	S3 F3→F6 S6→S9 F9‖F12 S12→S15 F15→F18 S18	T_2 → S3→F12 T_5 → F9→S18
	3-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18	T_2 → S3→S9→S15 T_5 → S6→S12→S18
	6-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18	T_2 → S3→F6→S9→F12→S15→F18 T_5 → F3→S6→F9→S12→F15→S18
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F2 S2	T_3 → S5 T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11‖F14 S14→S17 F17→F2 S2	T_3 → S5→F14 T_6 → F11→S2
	3-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F2 S2	T_3 → S5→S11→S17 T_6 → S8→S14→S2
	6-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F2 S2	T_3 → S5→F8→S11→F14→S17→F2 T_6 → F5→S8→F11→S14→F17→S2

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.
Δ Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.
F = finish of a group.
→ = connected to start or finish of a group.
‖ = spot for change with respect to series connection.
T-T = Top-to-top or bottom-to-bottom or short-jumper connection.

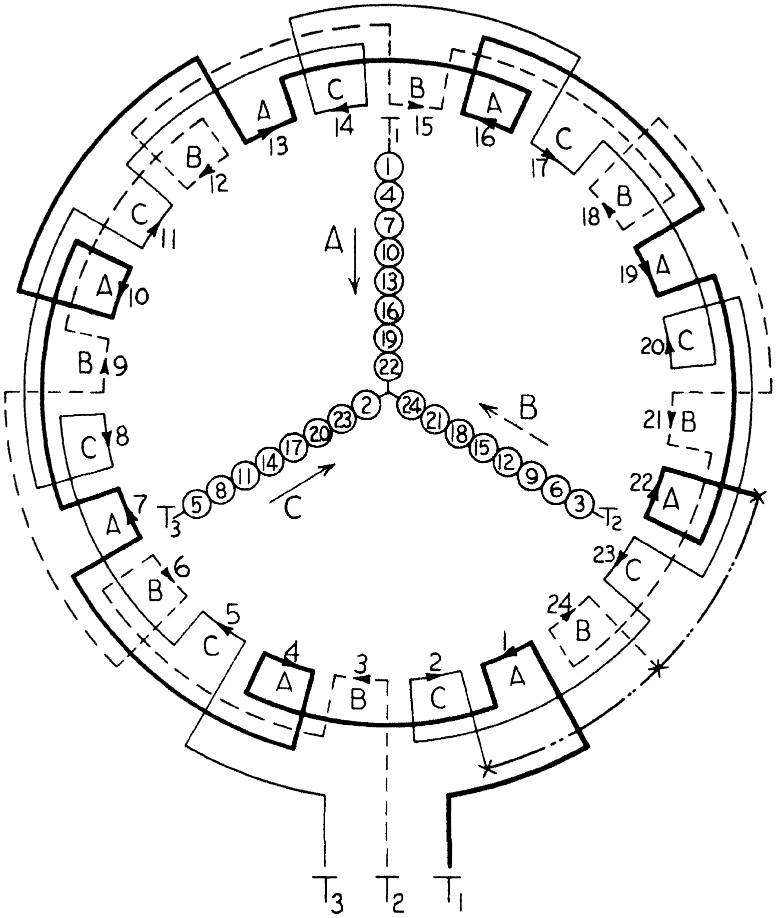


Fig. 3-65. 8-pole, 3-phase, series star connection diagram T-T

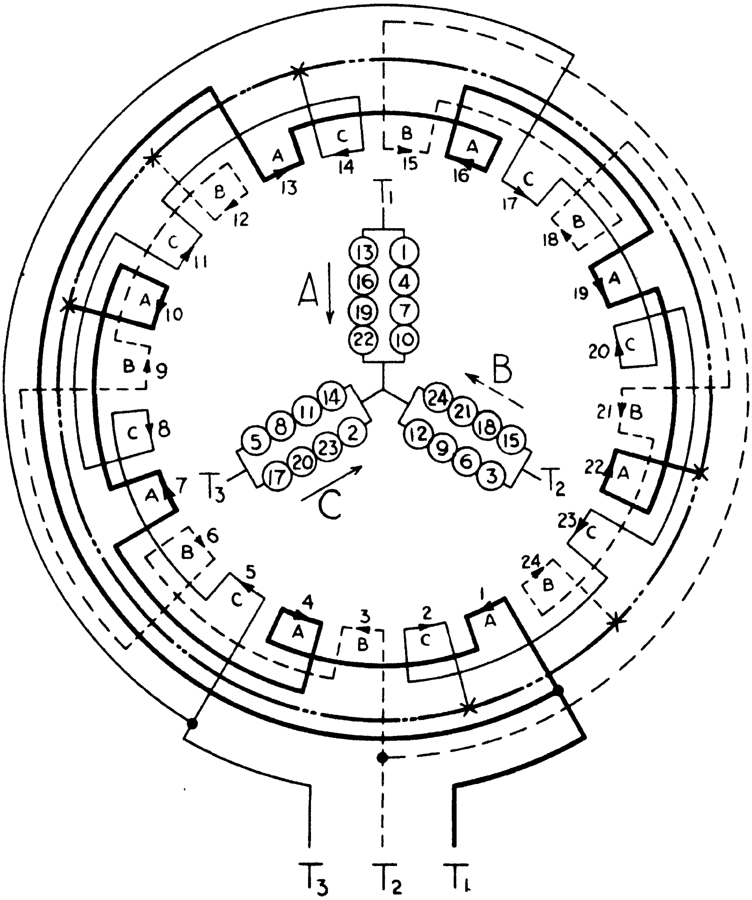


Fig. 3-66. 8-pole, 3-phase, 2-parallel star connection diagram T-T

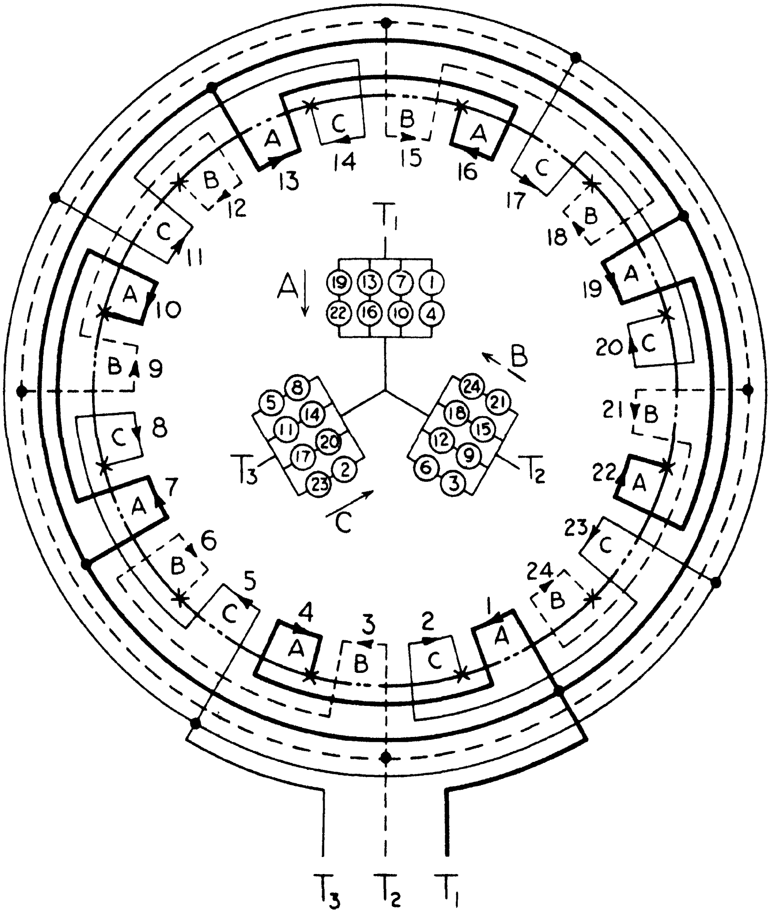


Fig. 3-67. 8-pole, 3-phase, 4-parallel star connection diagram T-T

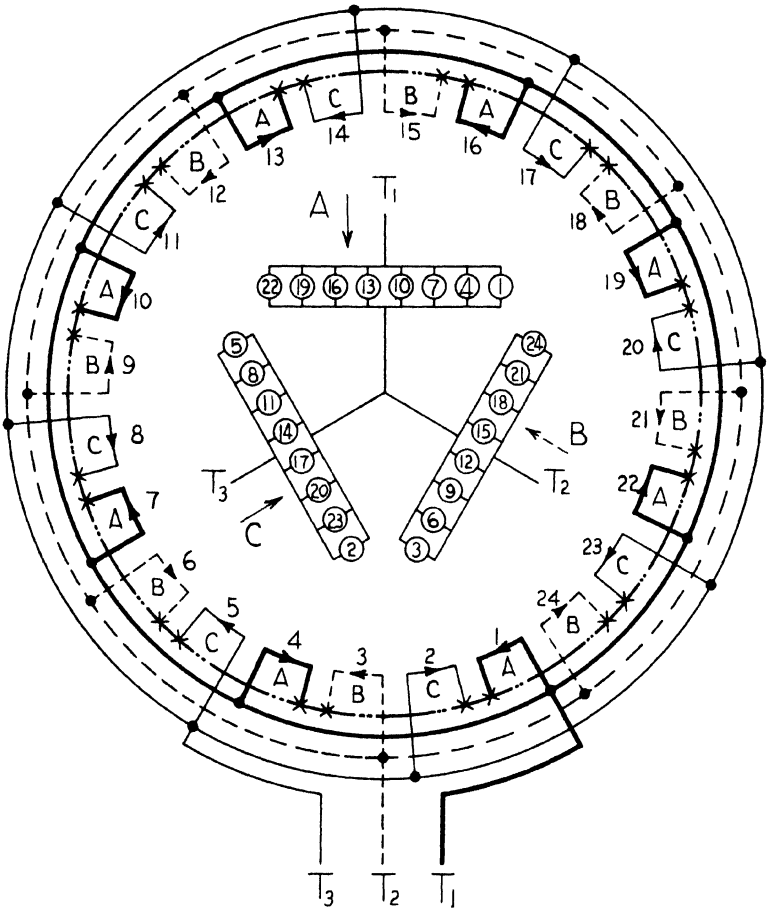


Fig. 3-68. 8-pole, 3-phase, 8-parallel star connection diagram

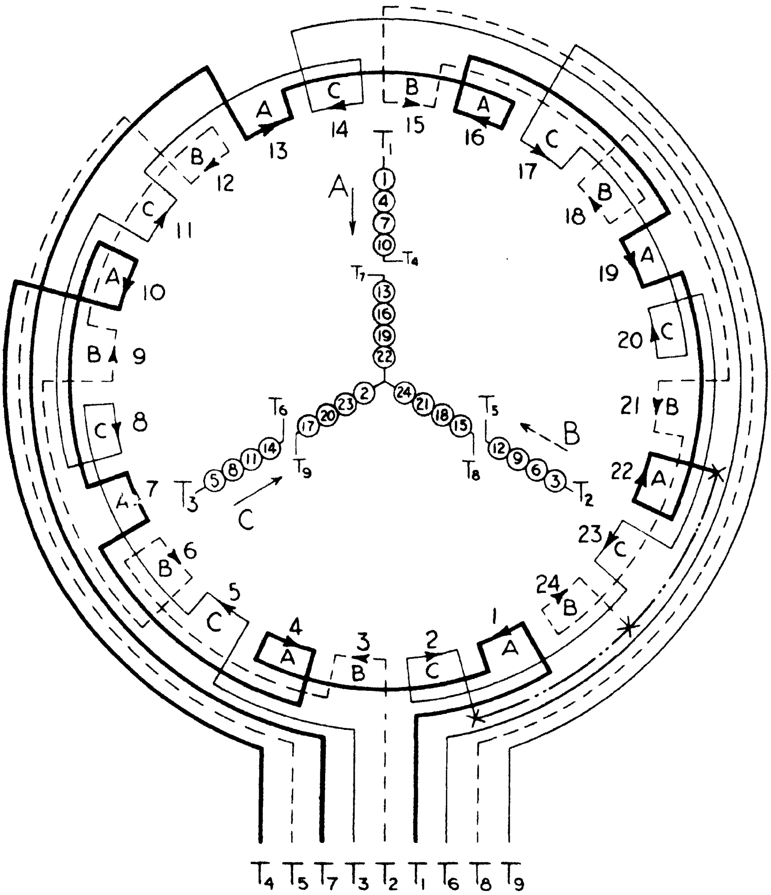


Fig. 3-69. 8-pole, 3-phase, series or 2-parallel star connection diagram with 9 leads T-T

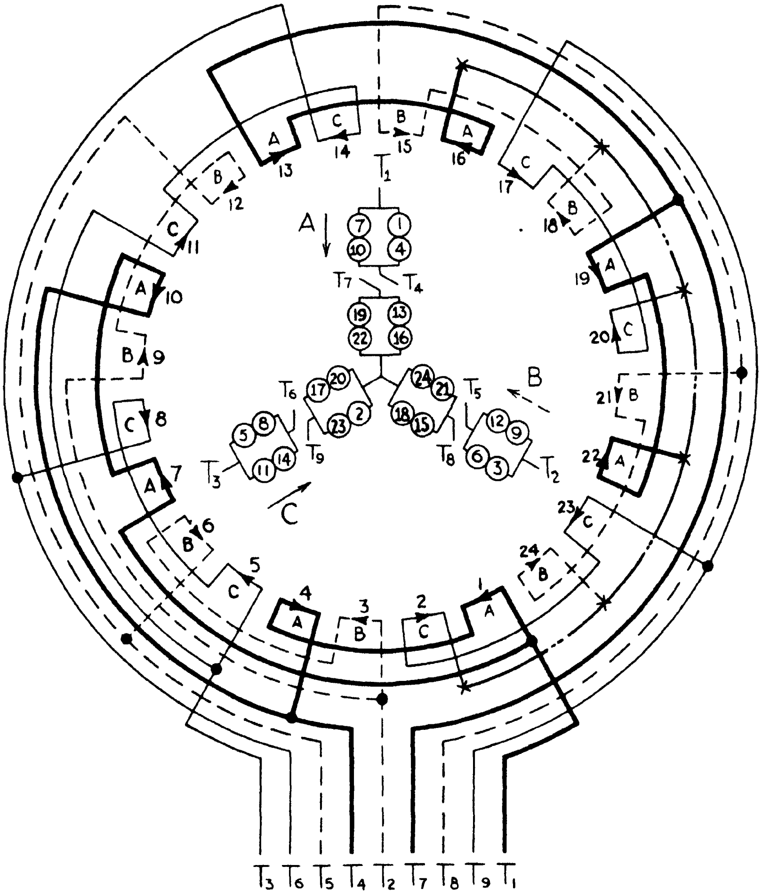


Fig. 3-70. 8-pole, 3-phase, 2- or 4-parallel star connection diagram with 9 leads T-T

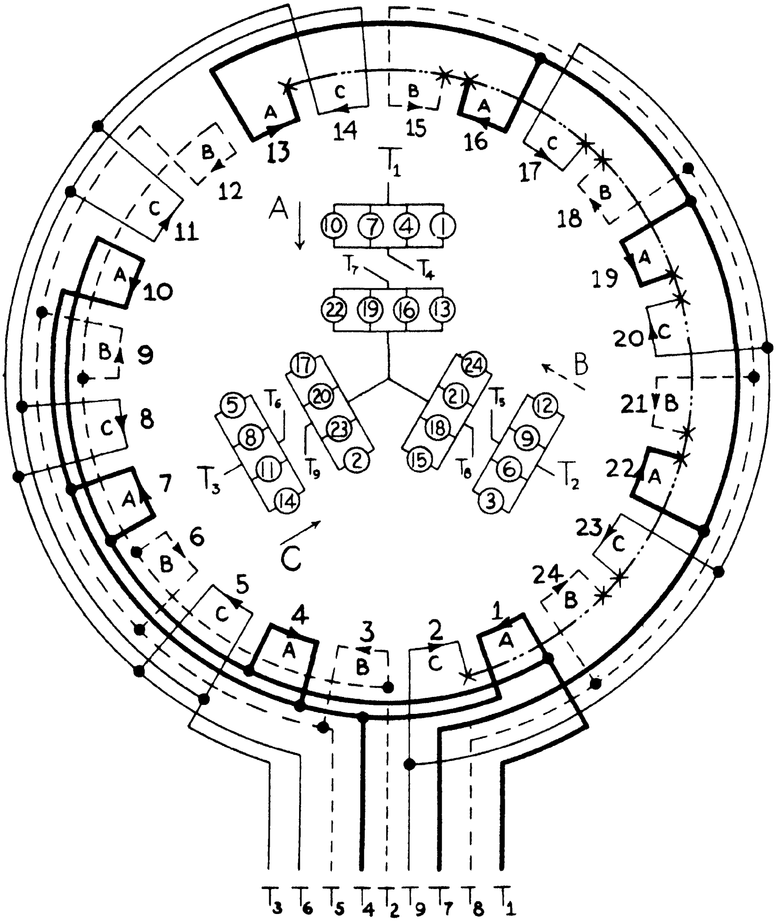


Fig. 3-71. 8-pole, 3-phase, 4- or 8-parallel star connection diagram with 9 leads T-T

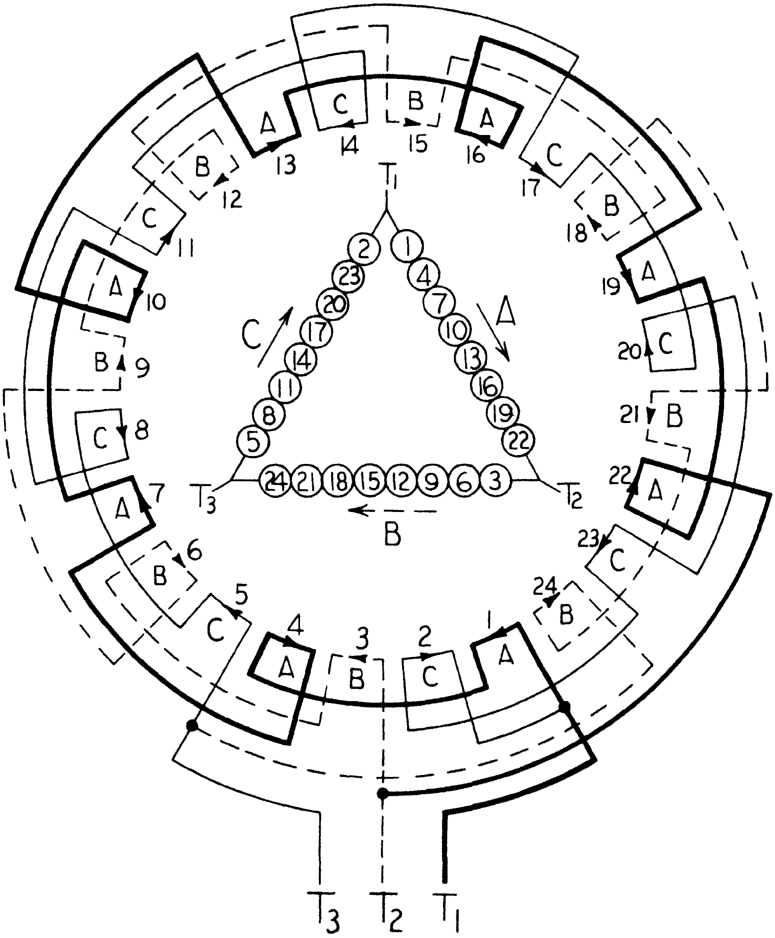


Fig. 3-72. 8-pole, 3-phase, series delta connection diagram T-T

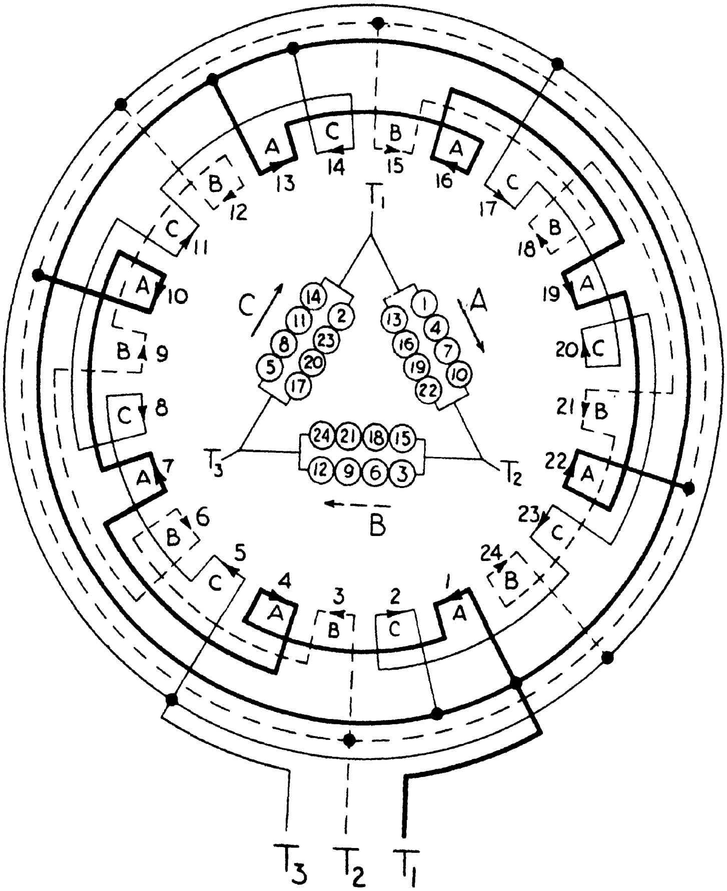


Fig. 3-73. 8-pole, 3-phase, 2-parallel delta connection diagram T-T

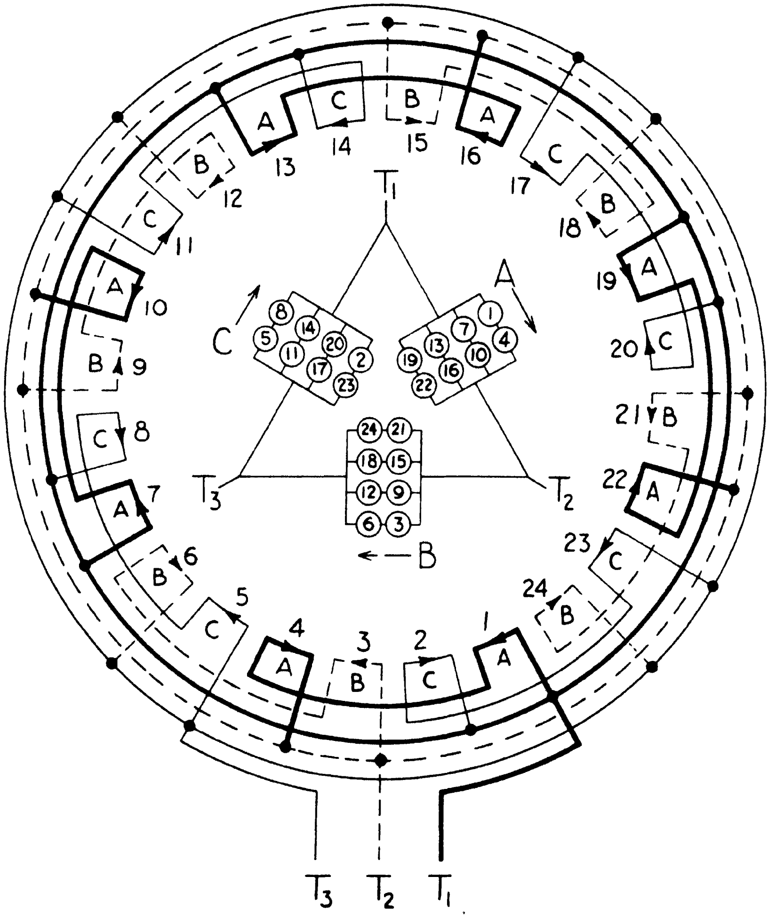


Fig. 3-74. 8-pole, 3-phase, 4-parallel delta connection diagram T-T

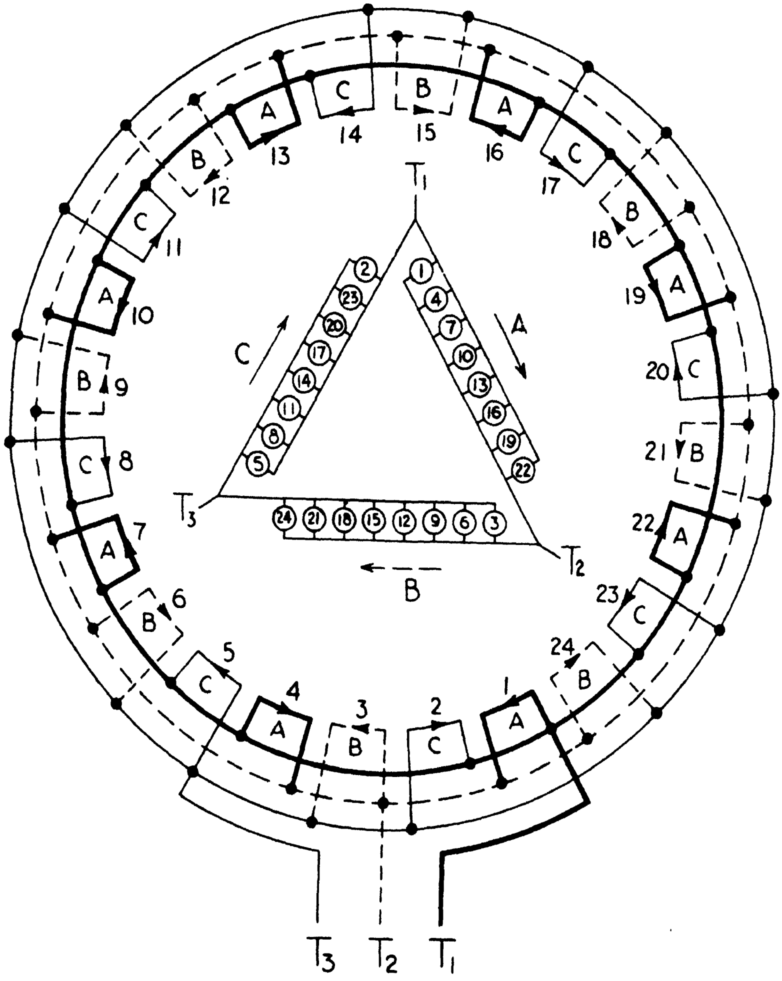


Fig. 3-75. 8-pole, 3-phase, 8-parallel delta connection diagram

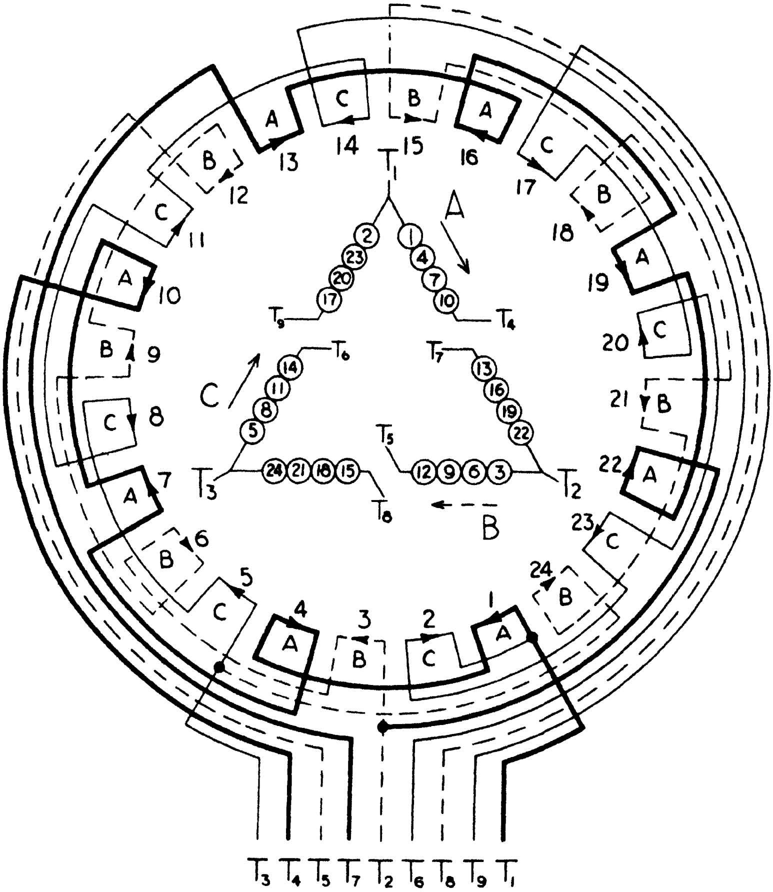


Fig. 3-76. 8-pole, 3-phase, series or 2-parallel delta connection diagram with 9 leads T-T

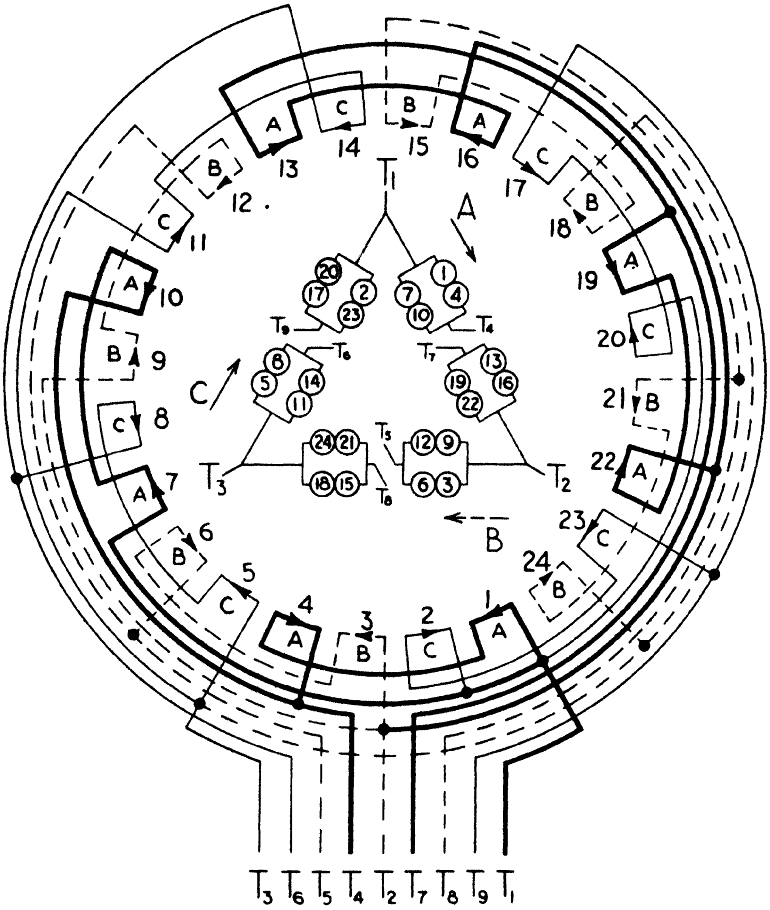


Fig. 3-77. 8-pole, 3-phase, 2- or 4-parallel delta connection diagram with 9 leads T-T

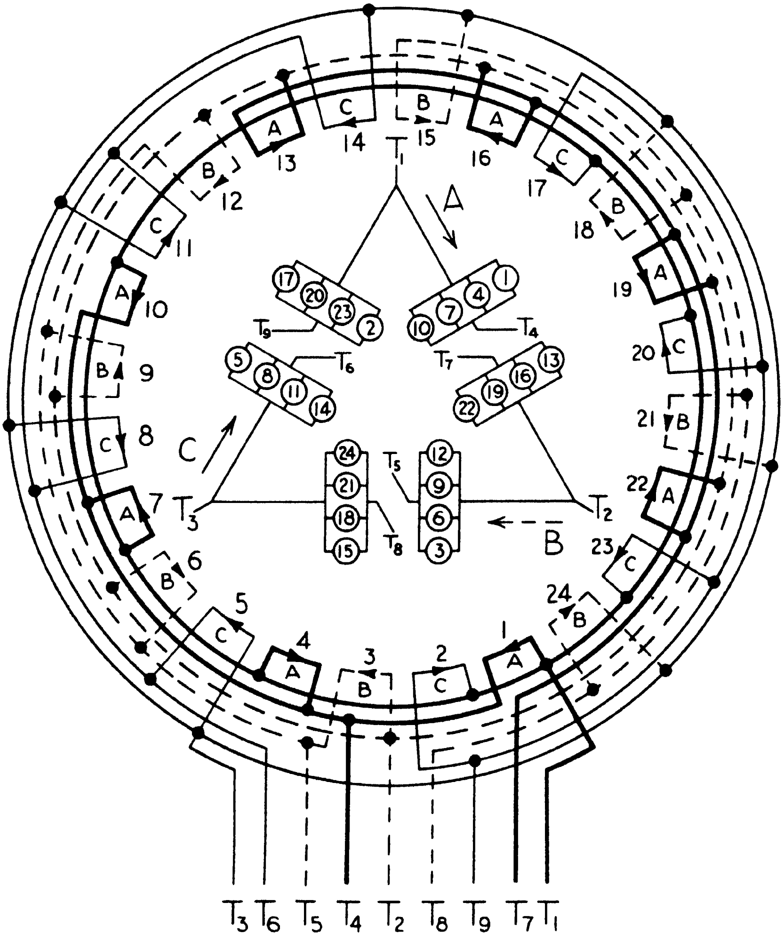


Fig. 3-78. 8-pole, 3-phase, 4- or 8-parallel delta connection diagram with 9 leads

TABLE 3-13

8-POLE 3-PHASE T-T CONNECTION TABLE

(Reference Connection Diagrams Figs. 3-65, 3-66, 3-67, 3-68, 3-72, 3-73, 3-74, 3-75)

Phase		Connections	Leads	
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22	T_1 → S1	T_4 → S22
	2-parallel	S1 F1→F4 S4→S7 F7→F10 S10‖S13 F13→F16 S16→S19 F19→F22 S22	T_1 → S1→S13	T_4 → S10→S22
	4-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22	T_1 → S1→S7→S13→S19	T_4 → S4→S10→S16→S22
	8-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22	T_1 → S1→F4→S7→F10→S13→F16→S19→F22 T_1 → F1→S4→F7→S10→F13→S16→F19→S22	
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24	T_2 → S3	T_5 → S24
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12‖S15 F15→F18 S18→S21 F21→F24 S24	T_2 → S3→S15	T_5 → S12→S24
	4-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24	T_2 → S3→S9→S15→S21	T_5 → S6→S12→S18→S24
	8-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24	T_2 → S3→F6→S9→F12→S15→F18→S21→F24 T_5 → F3→S6→F9→S12→F15→S18→F21→S24	
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F2 S2	T_3 → S5	T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14‖S17 F17→F20 S20→S23 F23→F2 S2	T_3 → S5→S17	T_6 → S14→S2
	4-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F2 S2	T_3 → S5→S11→S17→S23	T_6 → S8→S14→S20→S2
	8-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S2	

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Δ Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

T-T = Top-to-top or bottom-to-bottom or short-jumper connection.

→ = connected to start or finish of a group.

‖ = spot for change with respect to series connection

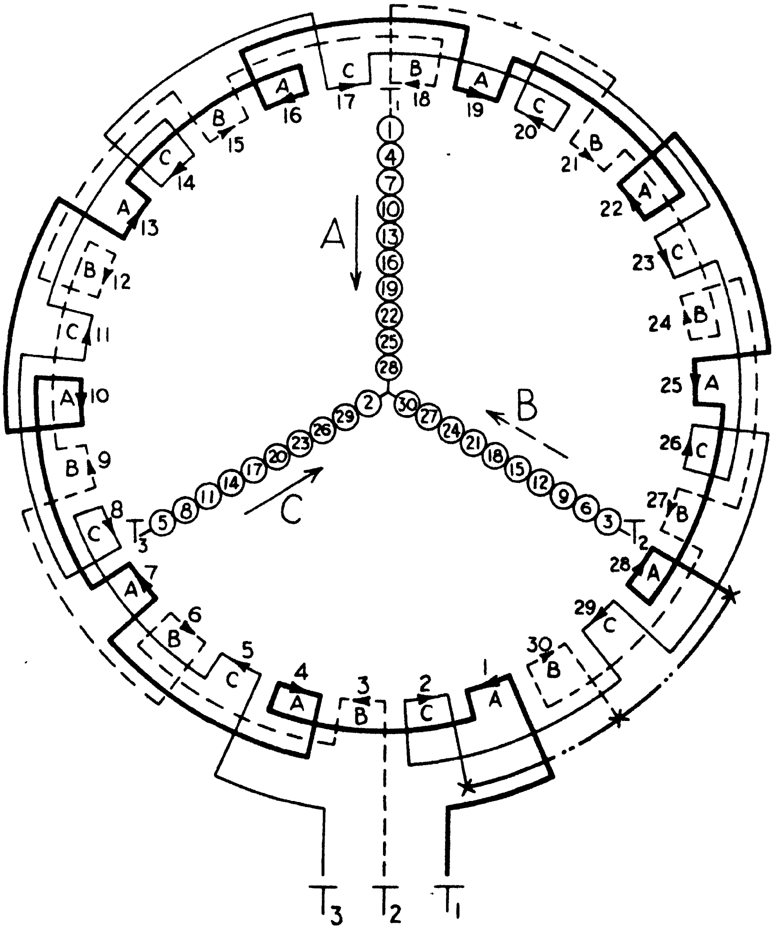


Fig. 3-79. 10-pole, 3-phase, series star connection diagram T-T

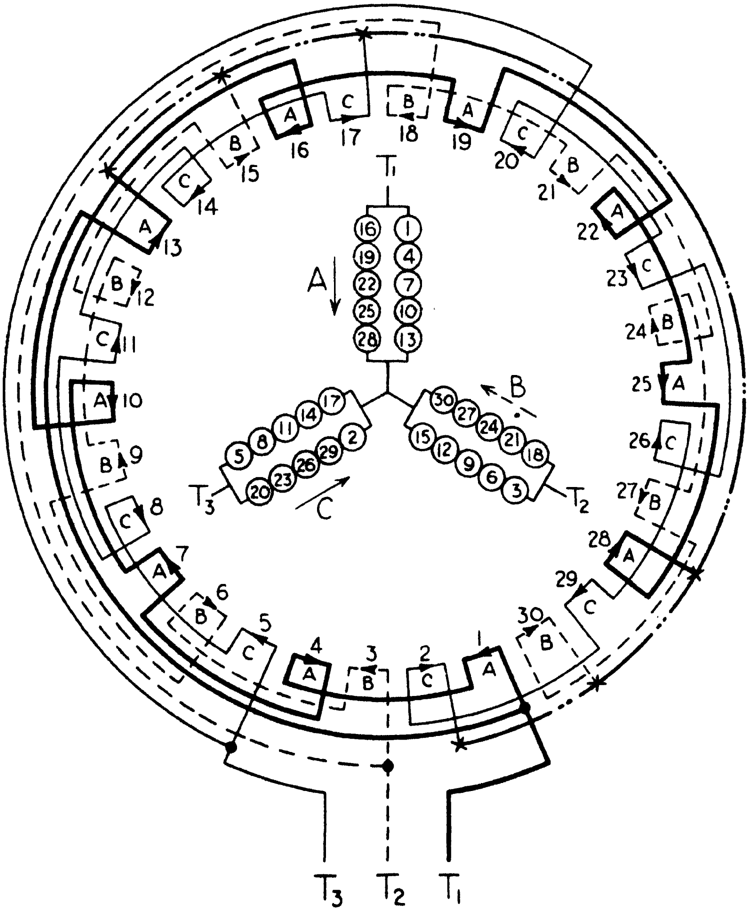


Fig. 3-80. 10-pole, 3-phase, 2-parallel star connection diagram

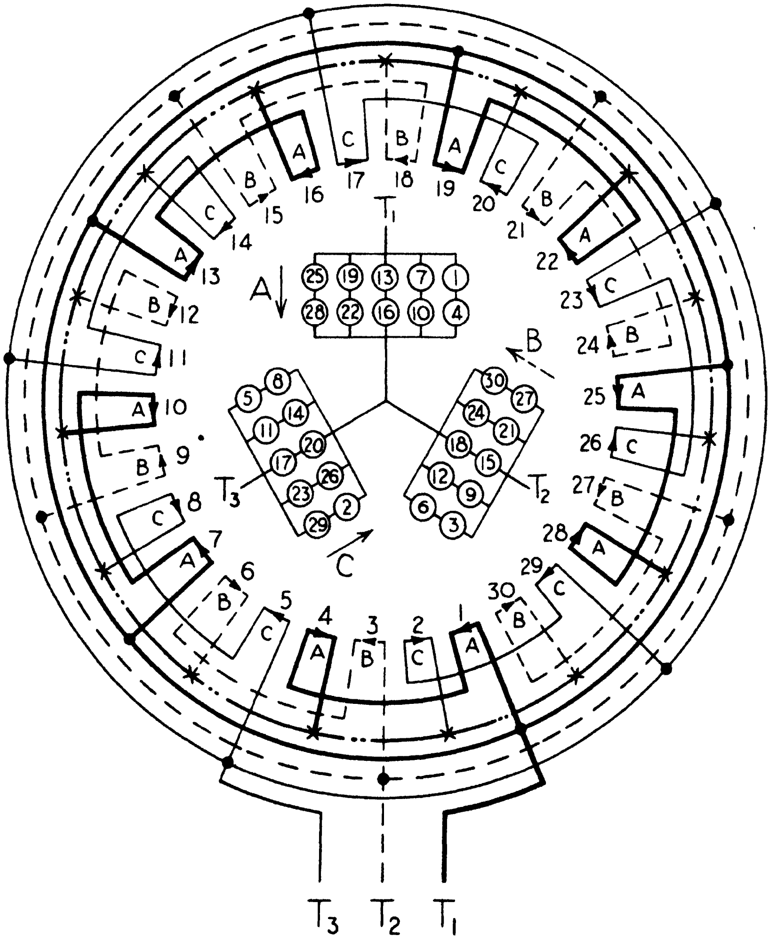


Fig. 3-81. 10-pole, 3-phase, 5-parallel star connection diagram T-T

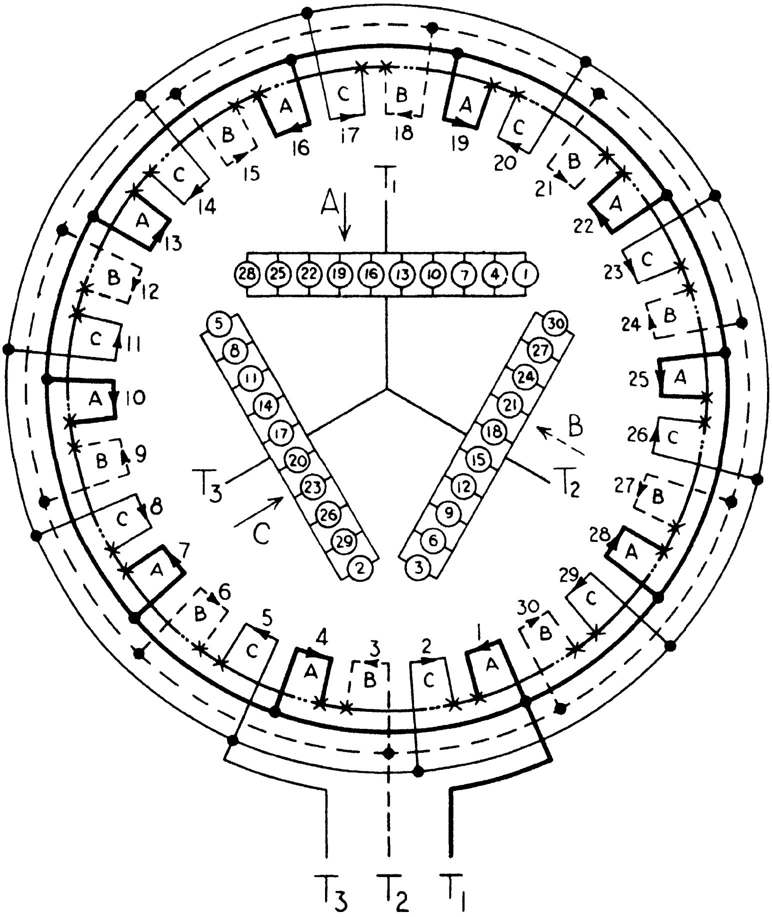


Fig. 3-82. 10-pole, 3-phase, 10-parallel star connection diagram

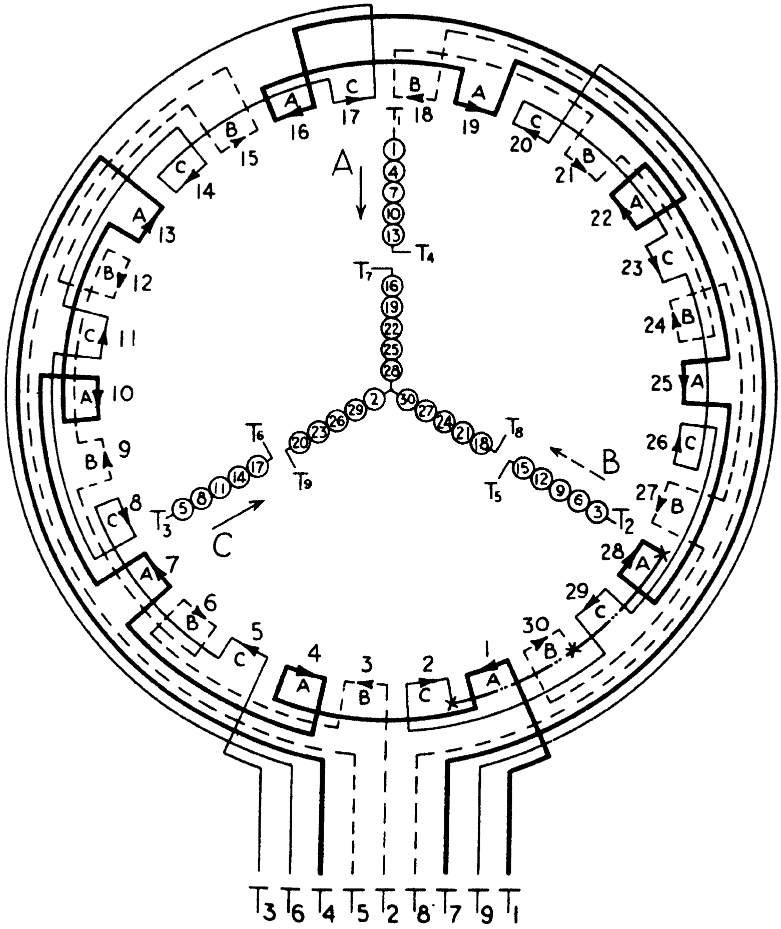


Fig. 3-83. 10-pole, 3-phase, series or 2-parallel star connection with 9 leads T-T

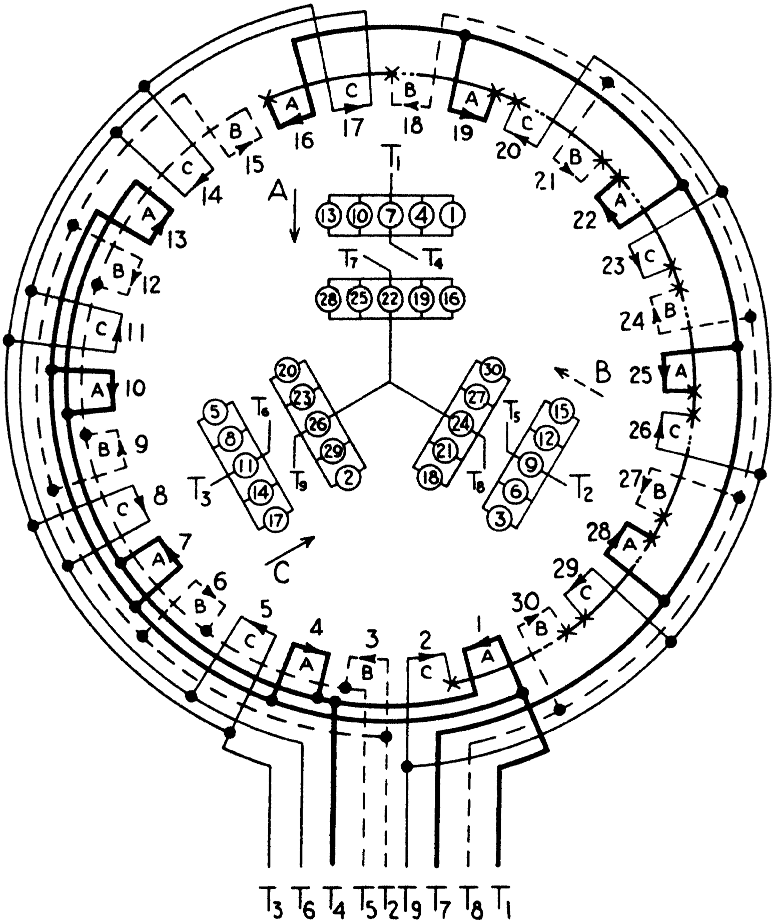


Fig. 3-84. 10-pole, 3-phase, 5- or 10-parallel star connection diagram with 9 leads

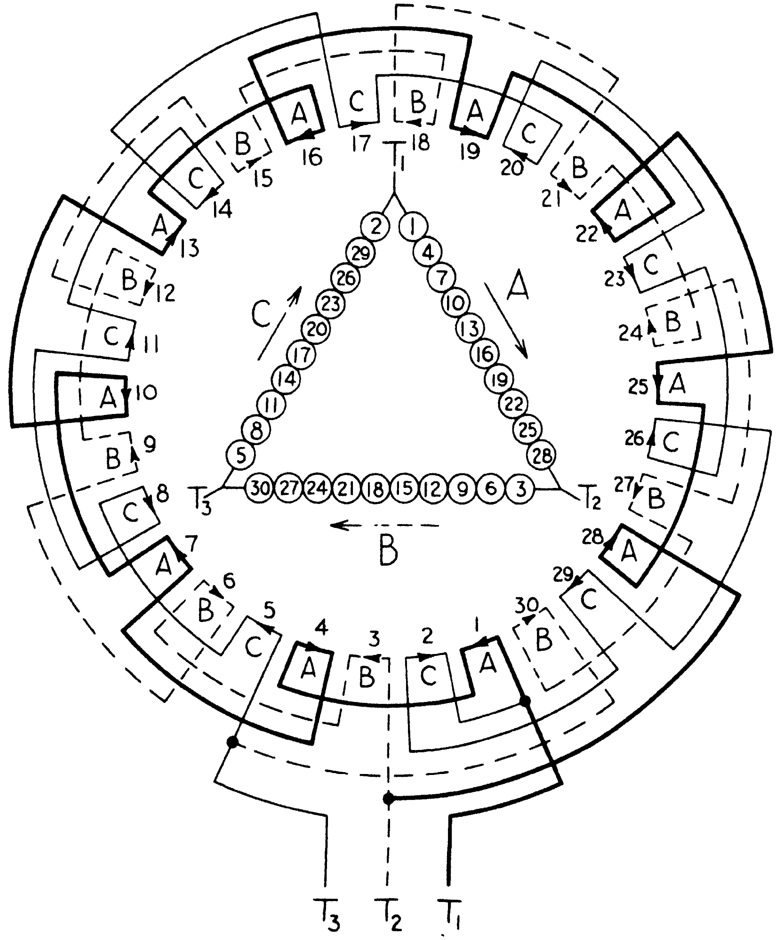


Fig. 3-85. 10-pole, 3-phase, series delta connection diagram T-T

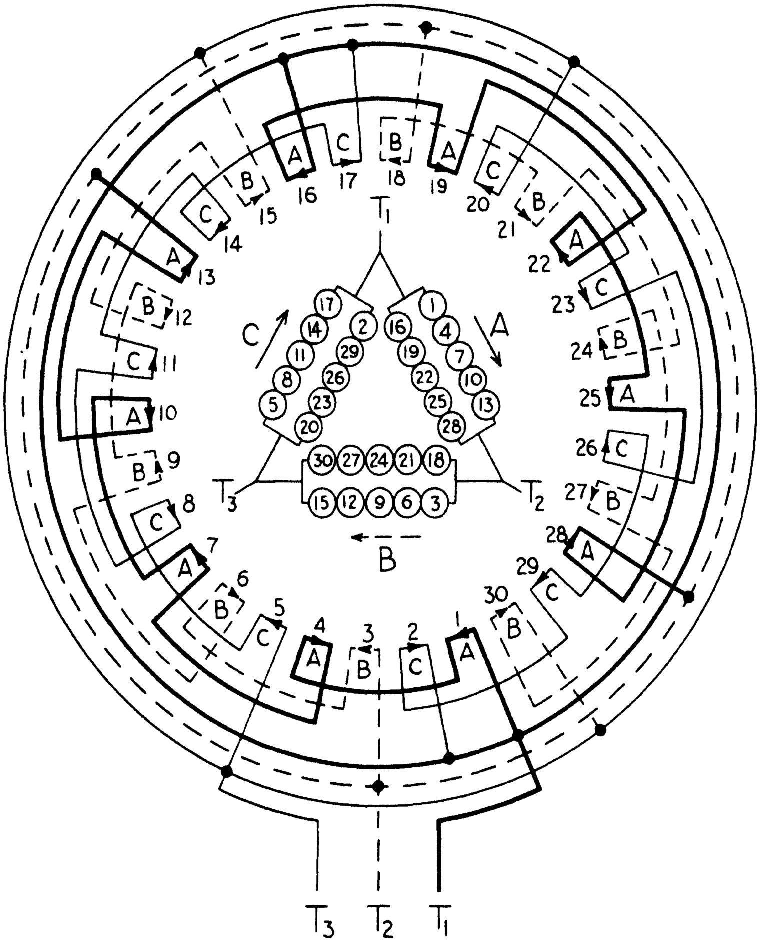


Fig. 3-86. 10-pole, 3-phase, 2-parallel delta connection diagram T-T

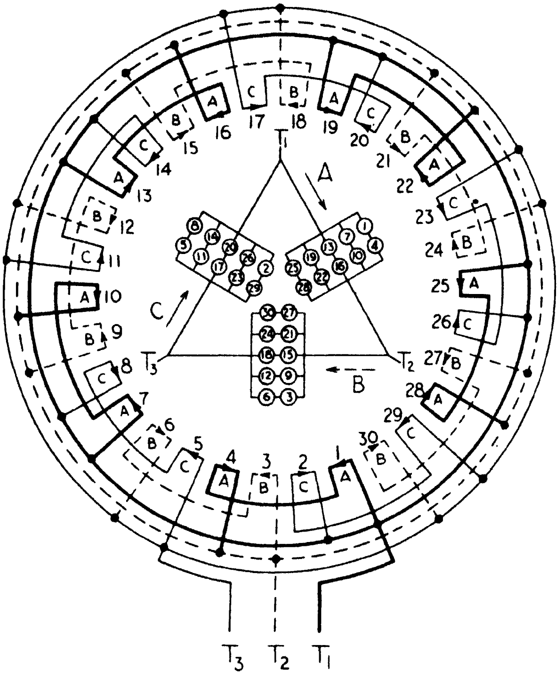


Fig. 3-87. 10-pole, 3-phase, 5-parallel delta connection diagram T-T

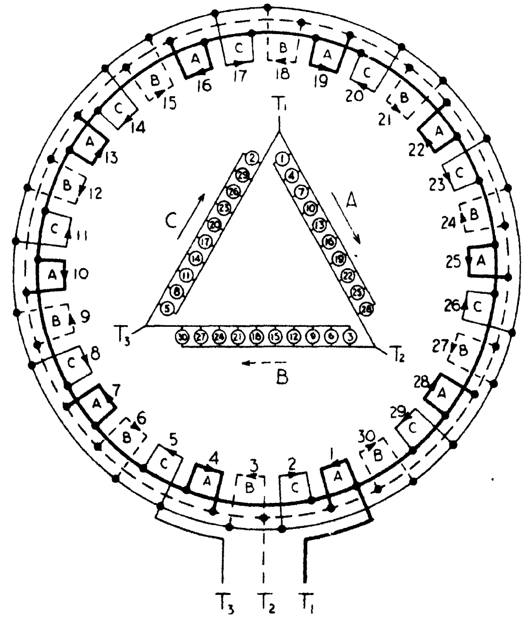


Fig. 3-88. 10-pole, 3-phase, 10-parallel delta connection diagram

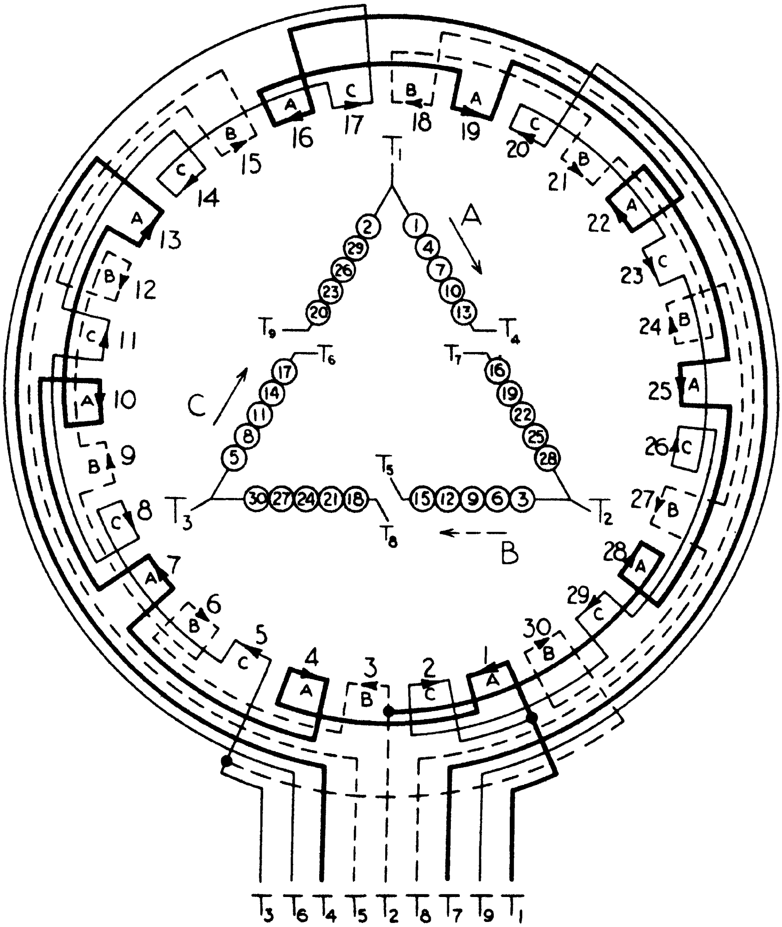


Fig. 3-89. 10-pole, 3-phase, series or 2-parallel delta connection diagram with 9 leads T-T

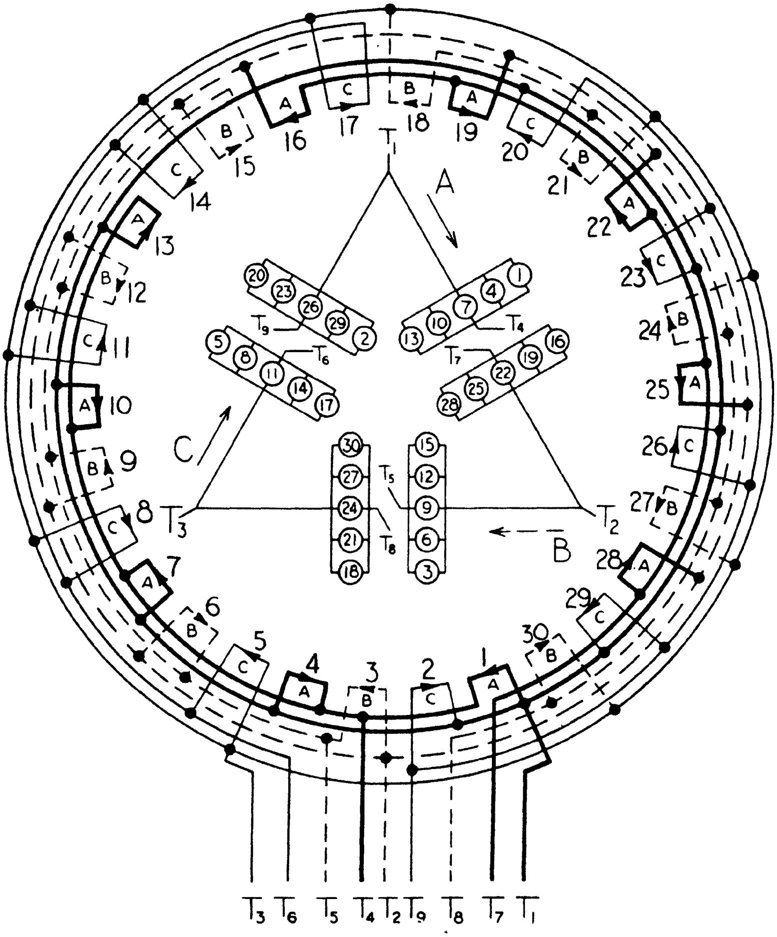


Fig. 3-90. 10-pole, 3-phase, 5- or 10-parallel delta connection diagram with 9 leads

TABLE 3-14

10-POLE 3-PHASE T-T CONNECTION TABLE

(Reference Connection Diagrams Figs. 3-70, 3-80, 3-81, 3-82, 3-85, 3-86, 3-87, 3-88)

Phase	Connections		Leads
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28	T_1 → S1 T_4 → S28
	2-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13‖F16 S16→S19 F19→F22 S22→S25 F25→F28 S28	T_1 → S1→F16 T_4 → F13→S28
	5-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22‖S25 F25→F28 S28	T_1 → S1→S7→S13→S19→S25 T_4 → S4→S10→S16→S22→S28
	10-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22‖S25 F25‖F28 S28	T_1 → S1→F4→S7→F10→S13→F16→S19→F22→S25→F28 T_4 → F1→S4→F7→S10→F13→S16→F19→S22→F25→S28
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30	T_2 → S3 T_5 → S30
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15‖F18 S18→S21 F21→F24 S24→S27 F27→F30 S30	T_2 → S3→F18 T_5 → F15→S30
	5-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24‖S27 F27→F30 S30	T_2 → S3→S9→S15→S21→S27 T_5 → S6→S12→S18→S24→S30
	10-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24‖S27 F27‖F30 S30	T_2 → S3→F6→S9→F12→S15→F18→S21→F24→S27→F30 T_5 → F3→S6→F9→S12→F15→S18→F21→S24→F27→S30
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F2 S2	T_3 → S5 T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17‖F20 S20→S23 F23→F26 S26→S29 F29→F2 S2	T_3 → S5→F20 T_6 → F17→S2
	5-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F26 S26‖S29 F29→F2 S2	T_3 → S5→S11→S17→S23→S29 T_6 → S8→S14→S20→S26→S2
	10-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F26 S26‖S29 F29‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F26→S29→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S26→F29→S2

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Δ Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

→ = connected to start or finish of a group.

‖ = spot for change with respect to series connection.

T-T = Top-to-top or bottom-to-bottom or short-jumper connection.

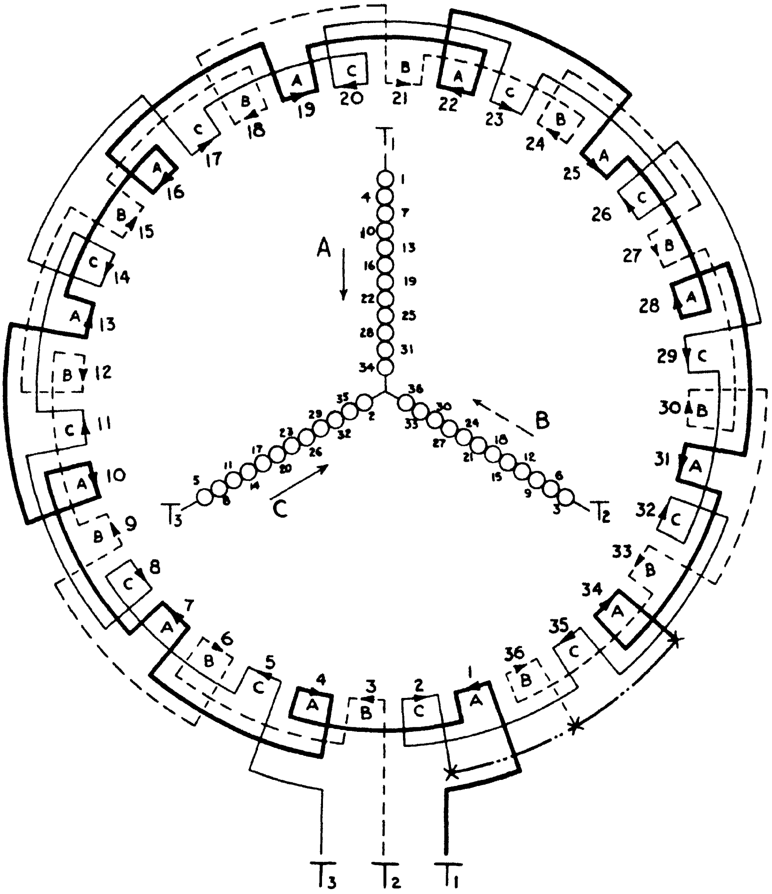


Fig. 3-91. 12-pole, 3-phase, series star connection diagram T-T

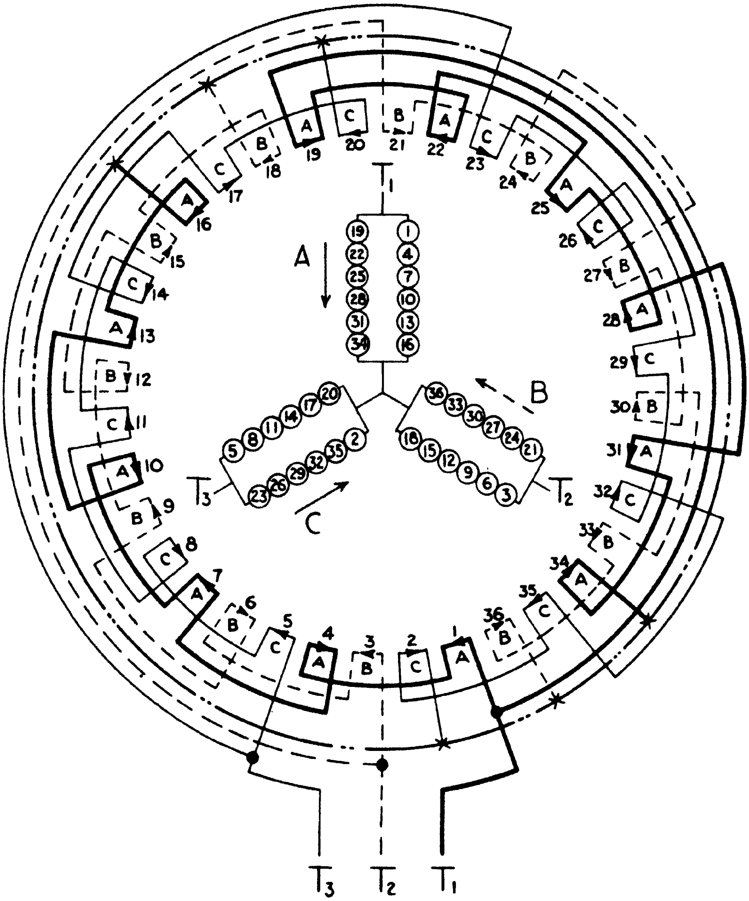


Fig. 3-92. 12-pole, 3-phase, 2-parallel star connection diagram T-T

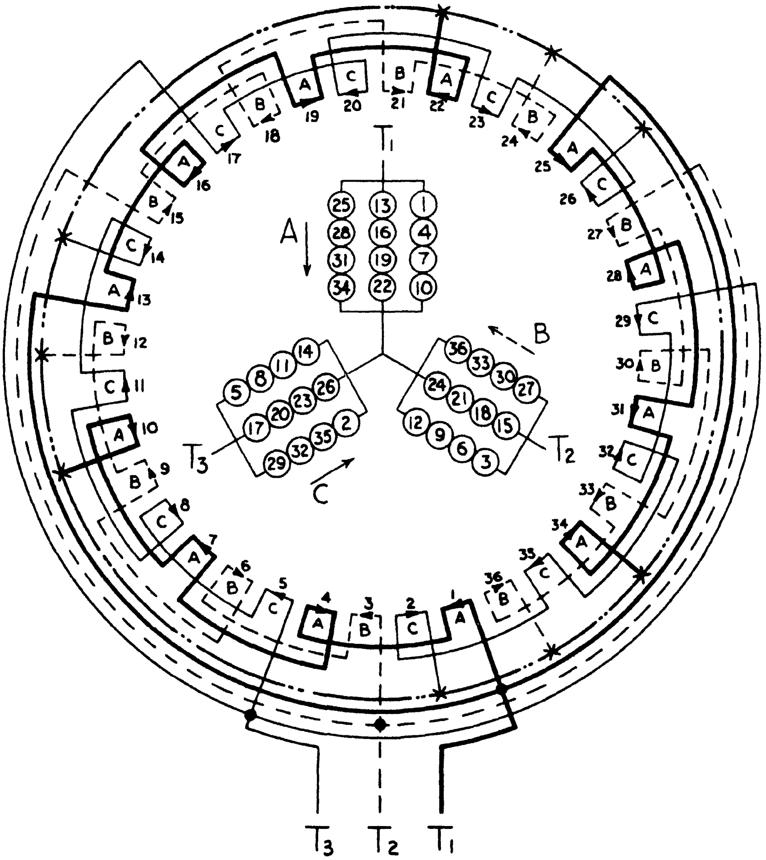


Fig. 3-93. 12-pole, 3-phase, 3-parallel star connection diagram T-T

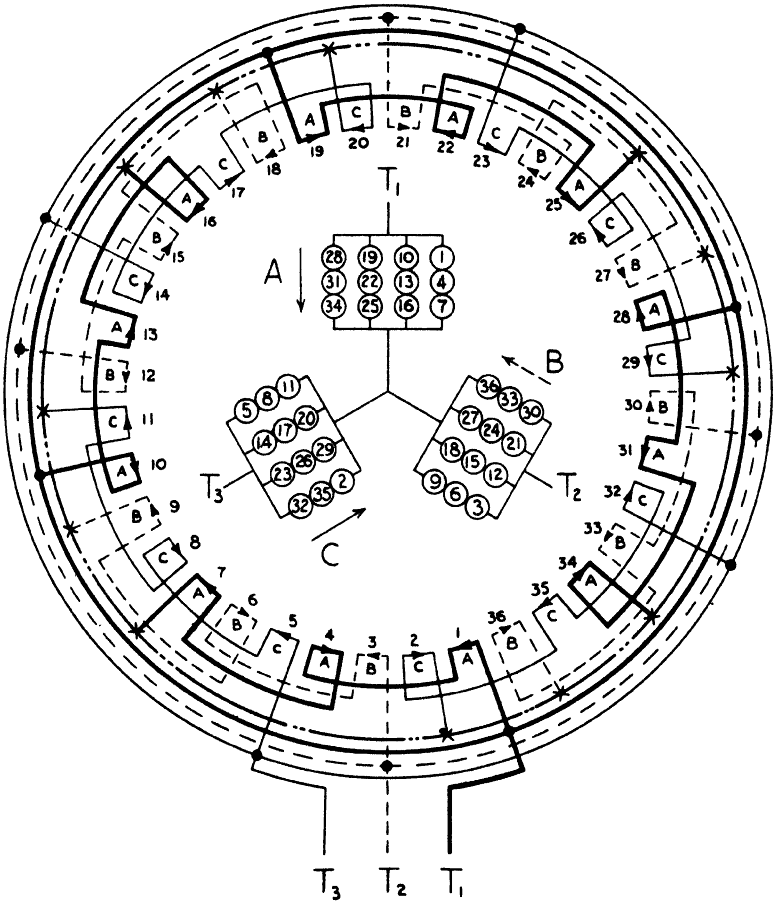


Fig. 3-94. 12-pole, 3-phase, 4-parallel star connection diagram T-T

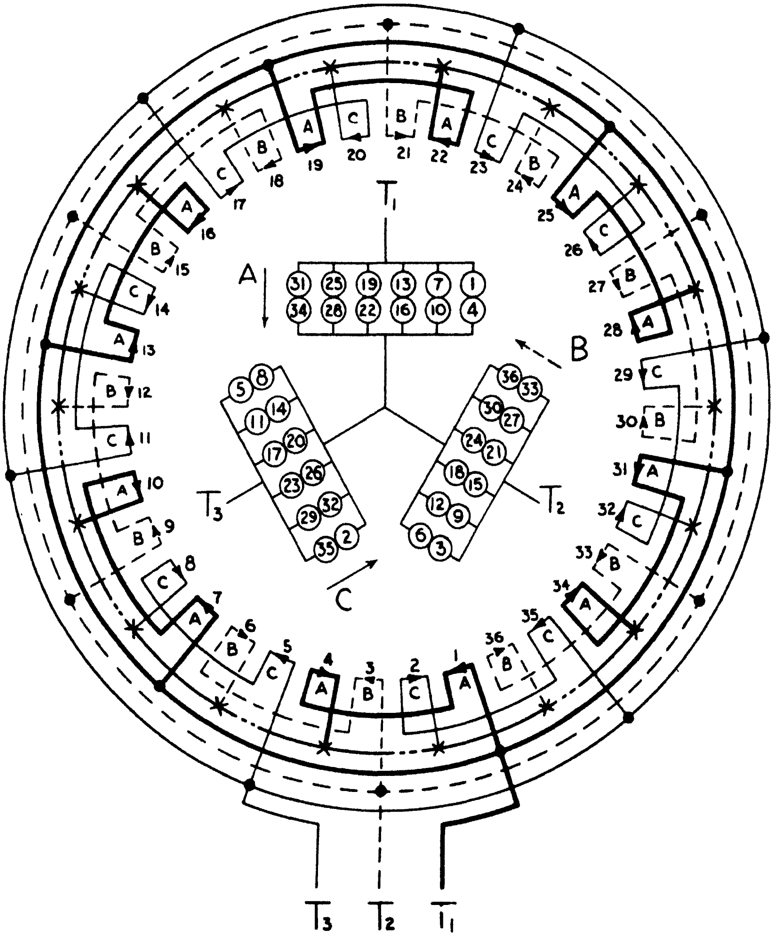


Fig. 3-95. 12-pole, 3-phase, 6-parallel star connection diagram T-T

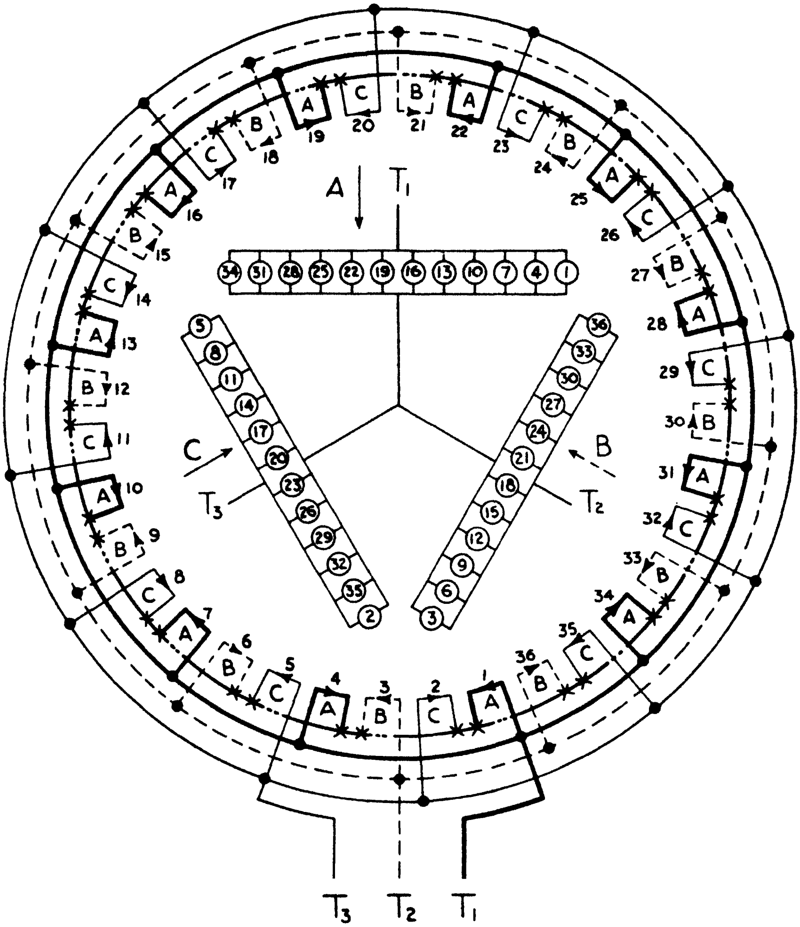


Fig. 3-96. 12-pole, 3-phase, 12-parallel star connection diagram

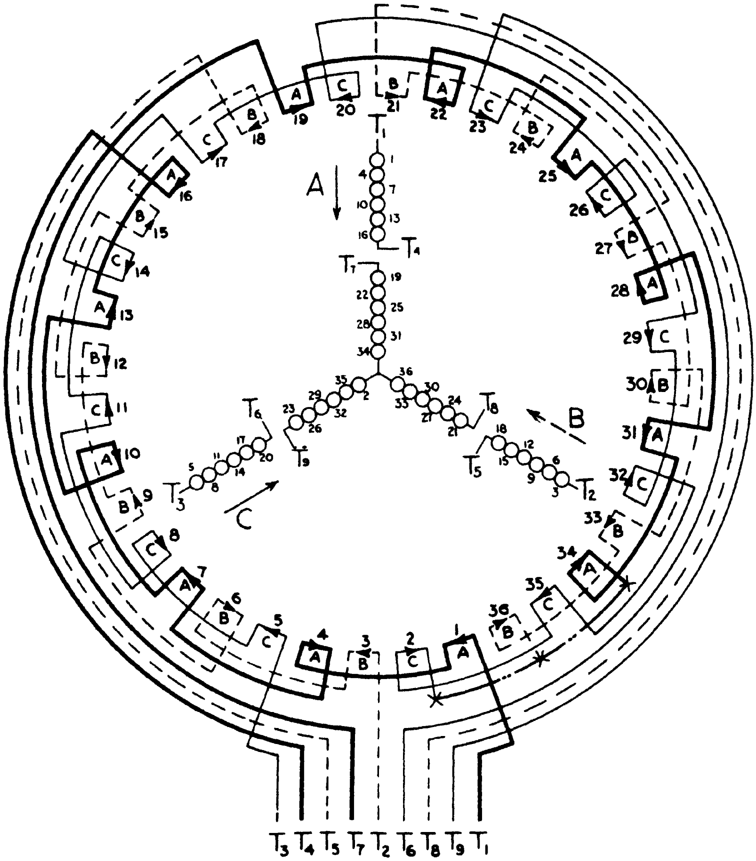


Fig. 3-97. 12-pole, 3-phase, series or 2-parallel star connection diagram with 9 leads T-T

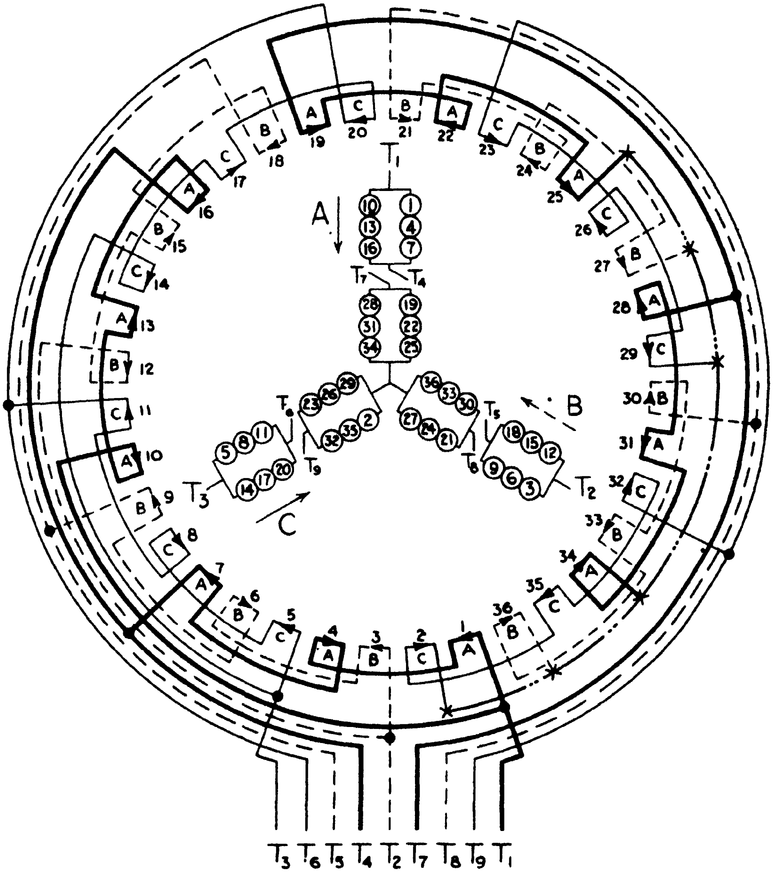


Fig. 3-98. 12-pole, 3-phase, 2- or 4-parallel star connection diagram with 9 leads T-T

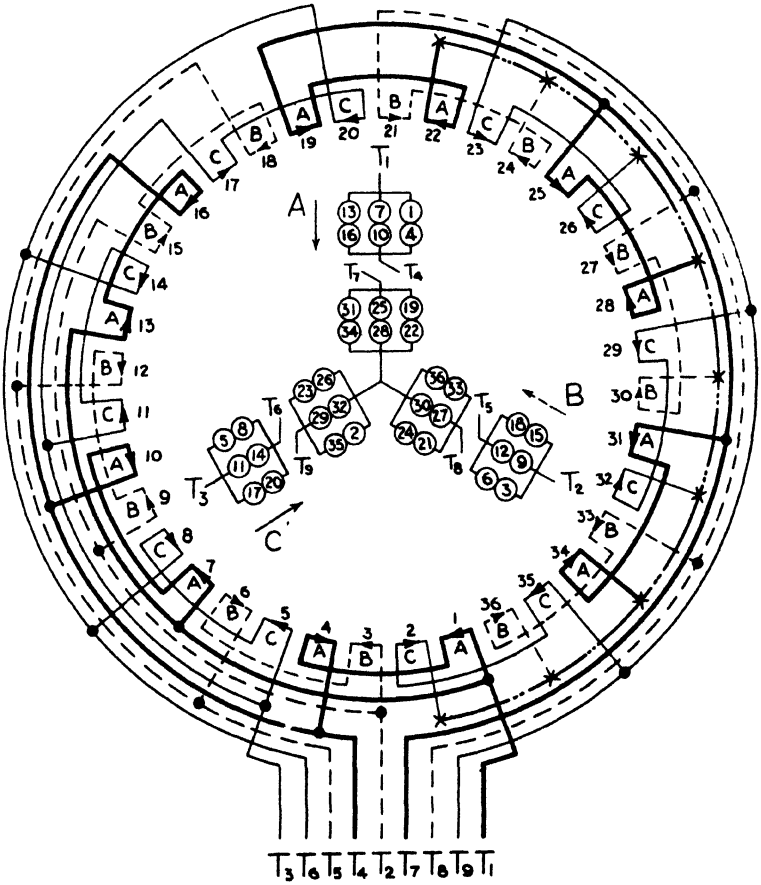


Fig. 3-99. 12-pole, 3-phase, 3- or 6-parallel star connection diagram with 9 leads T-T

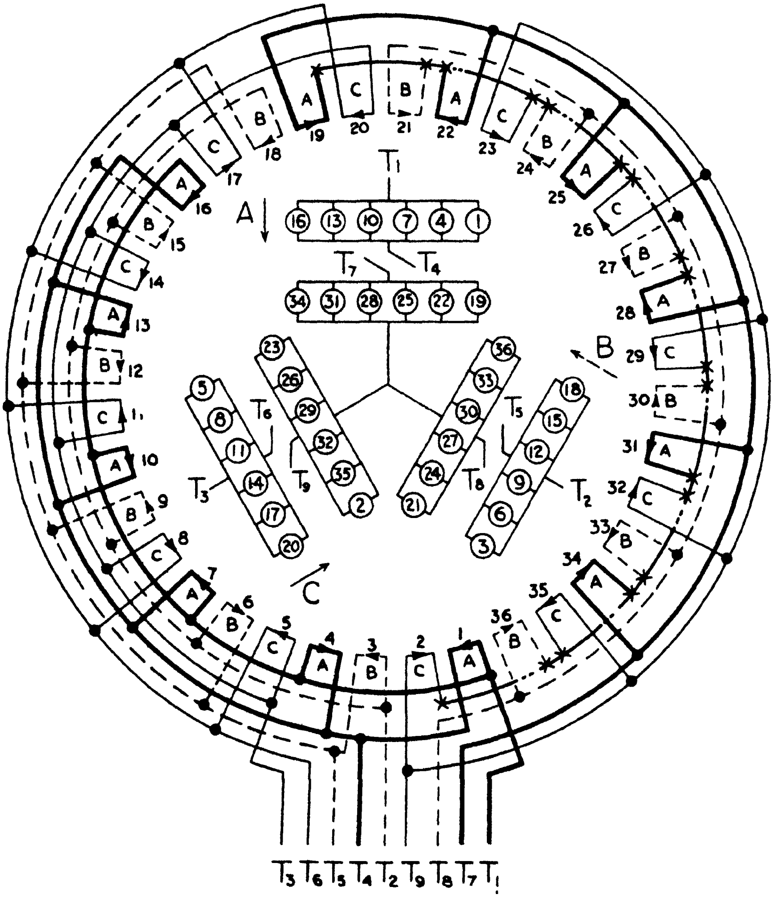


Fig. 3-100. 12-pole, 3-phase, 6- or 12-parallel star connection diagram with 9 leads

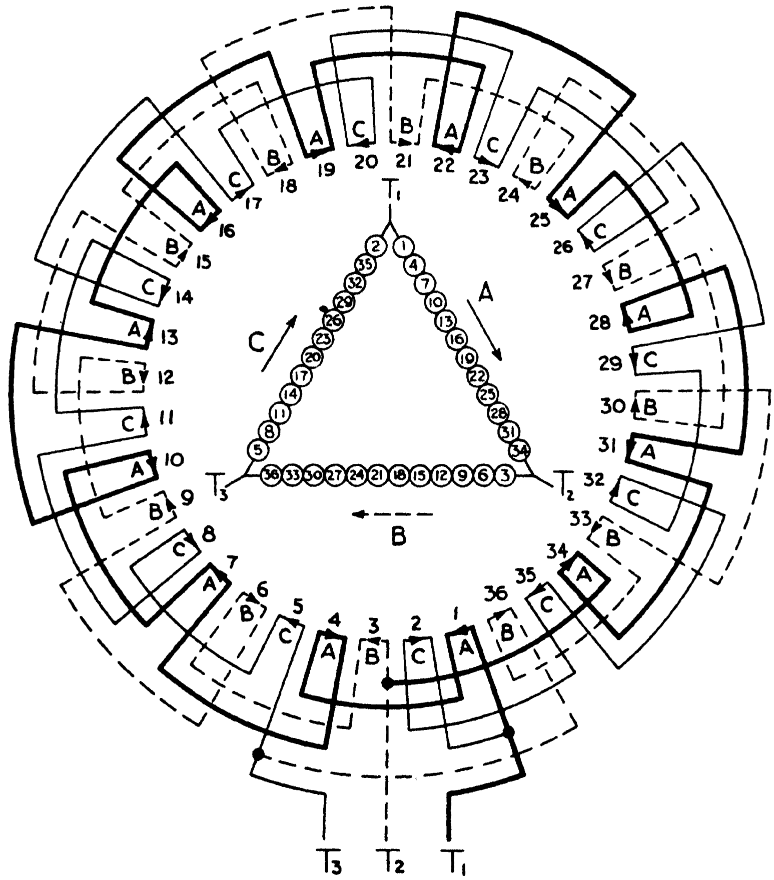


Fig. 3-101. 12-pole, 3-phase, series delta connection diagram T-T

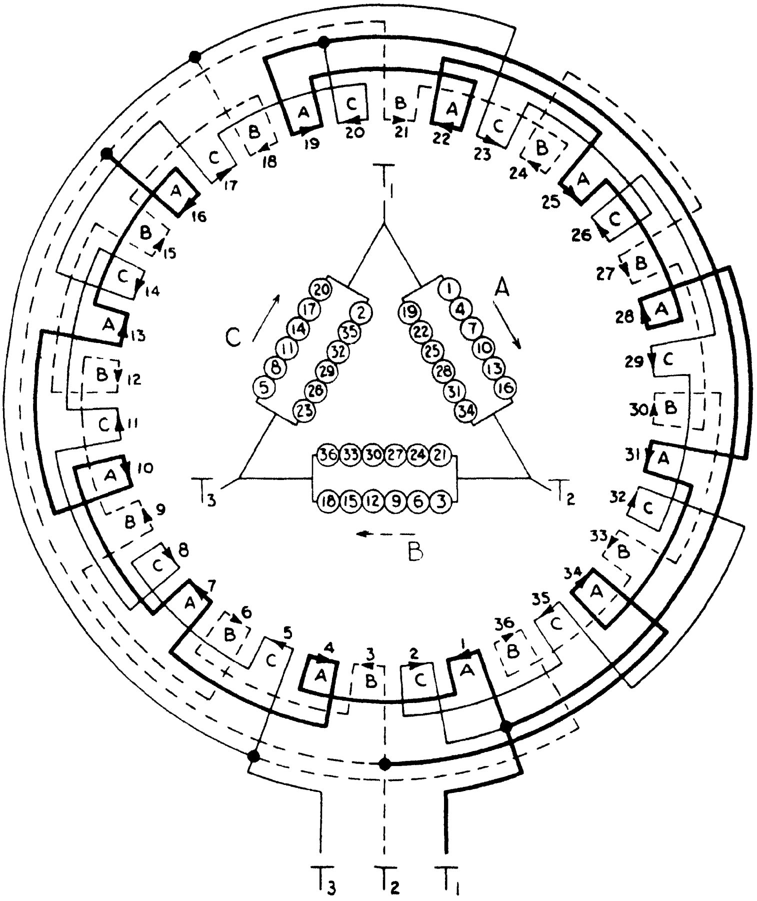


Fig. 3-102. 12-pole,3-phase,2-parallel delta connection diagram T-T

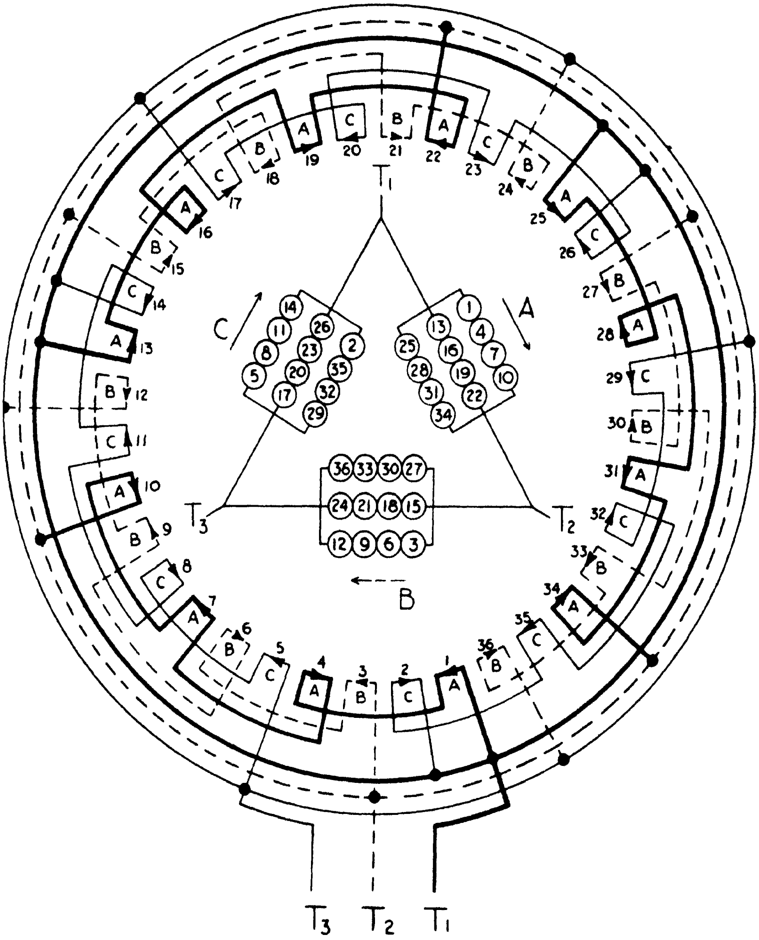


Fig. 3-103. 12-pole,3-phase,3-parallel delta connection diagram T-T

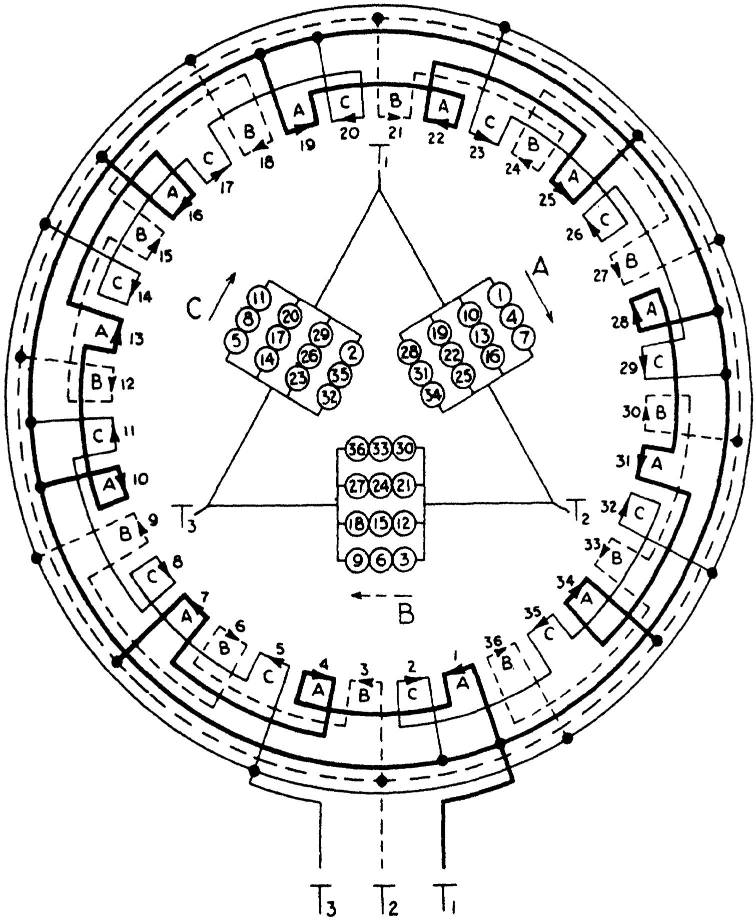


Fig. 3-104. 12-pole,3-phase,4-parallel delta connection diagram T-T

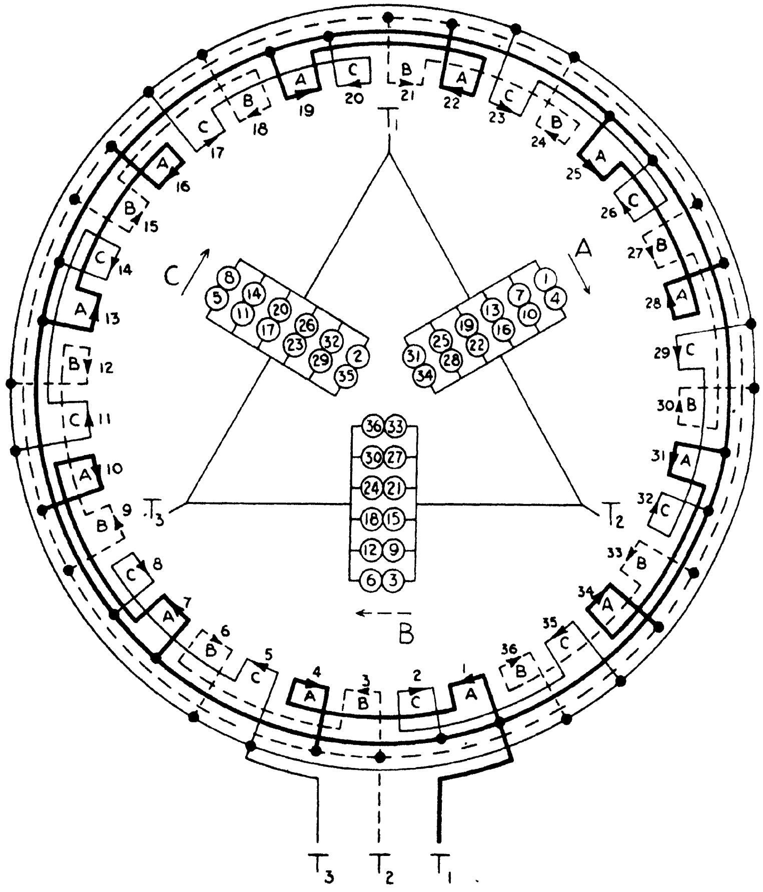


Fig. 3-105. 12-pole,3-phase,6-parallel delta connection diagram T-T

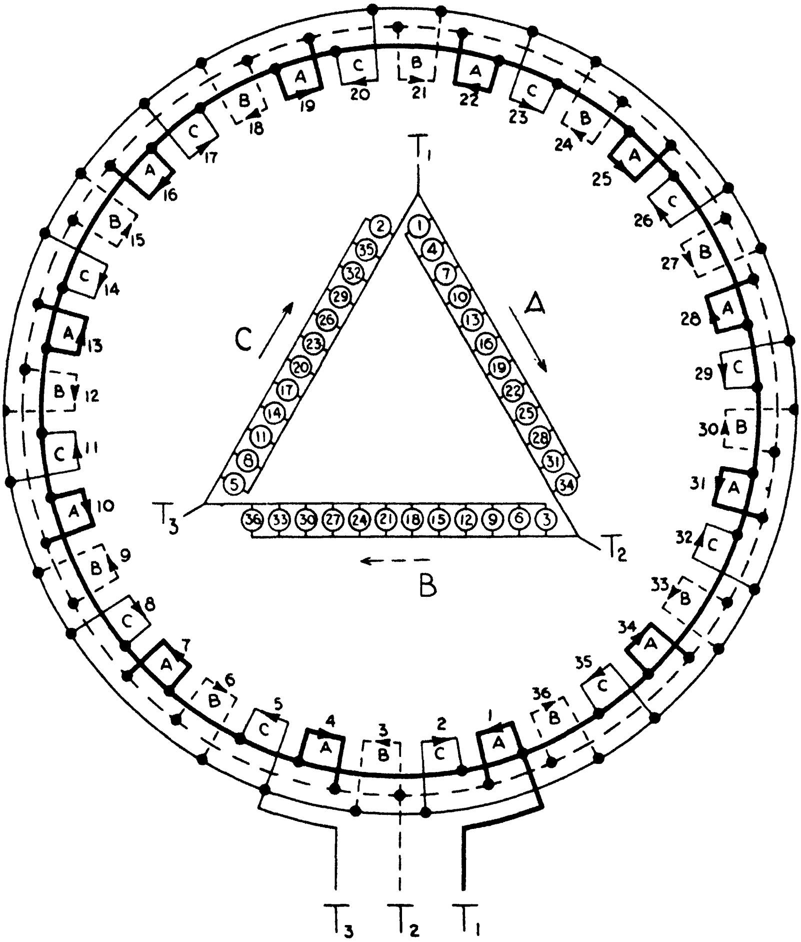


Fig. 3-106. 12-pole,3-phase,12-parallel delta connection diagram

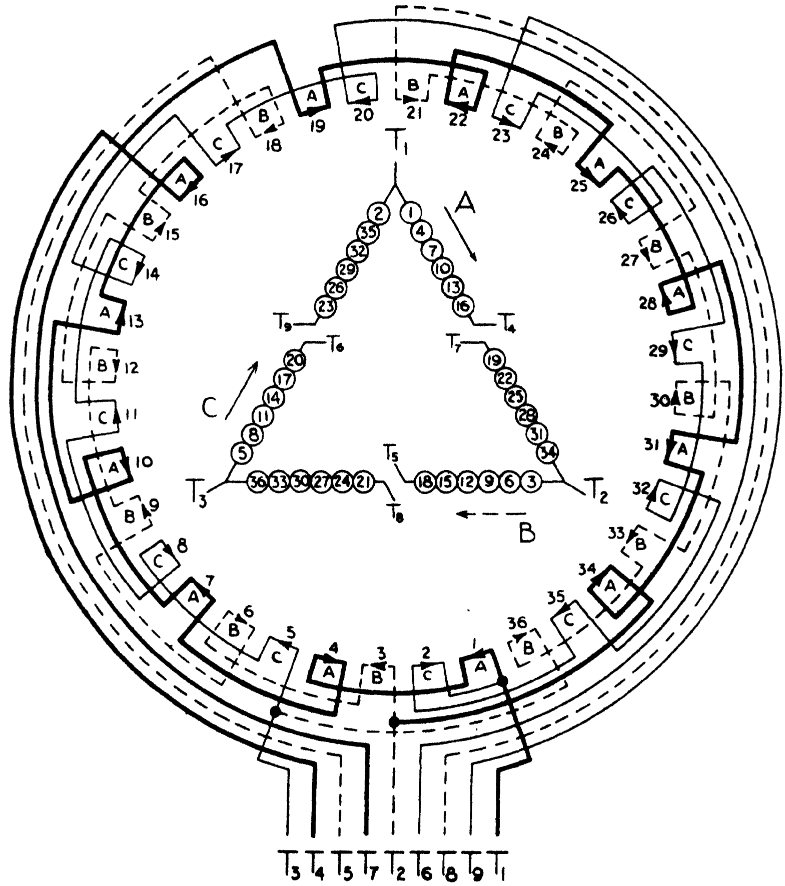


Fig. 3-107. 12-pole, 3-phase, series or 2-parallel delta connection diagram with 9 leads T-T

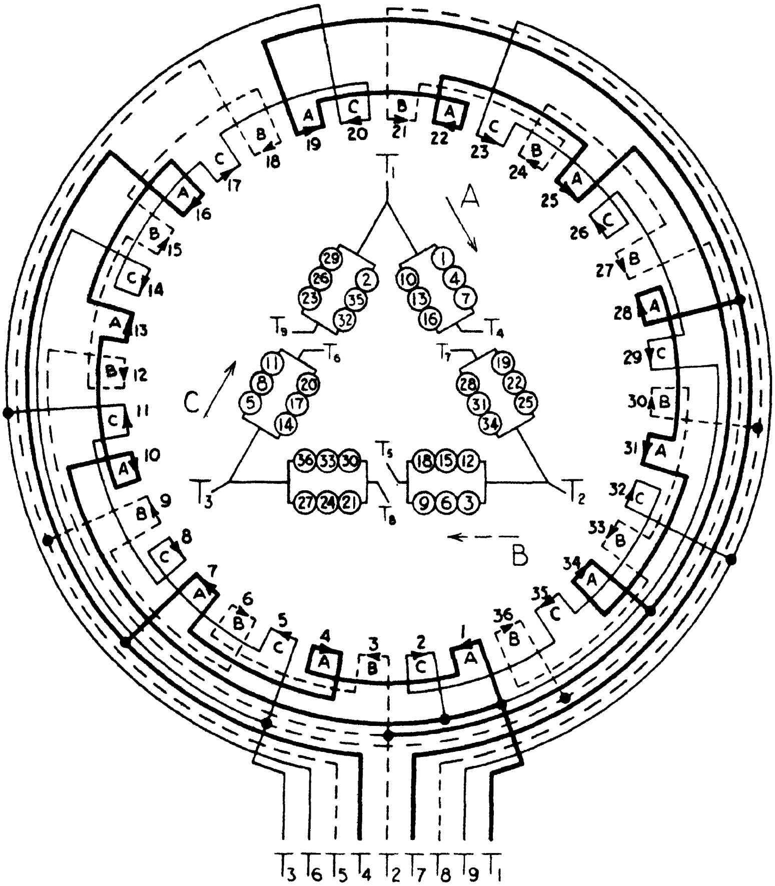


Fig. 3-108. 12-pole, 3-phase, 2- or 4-parallel delta connection diagram with 9 leads T-T

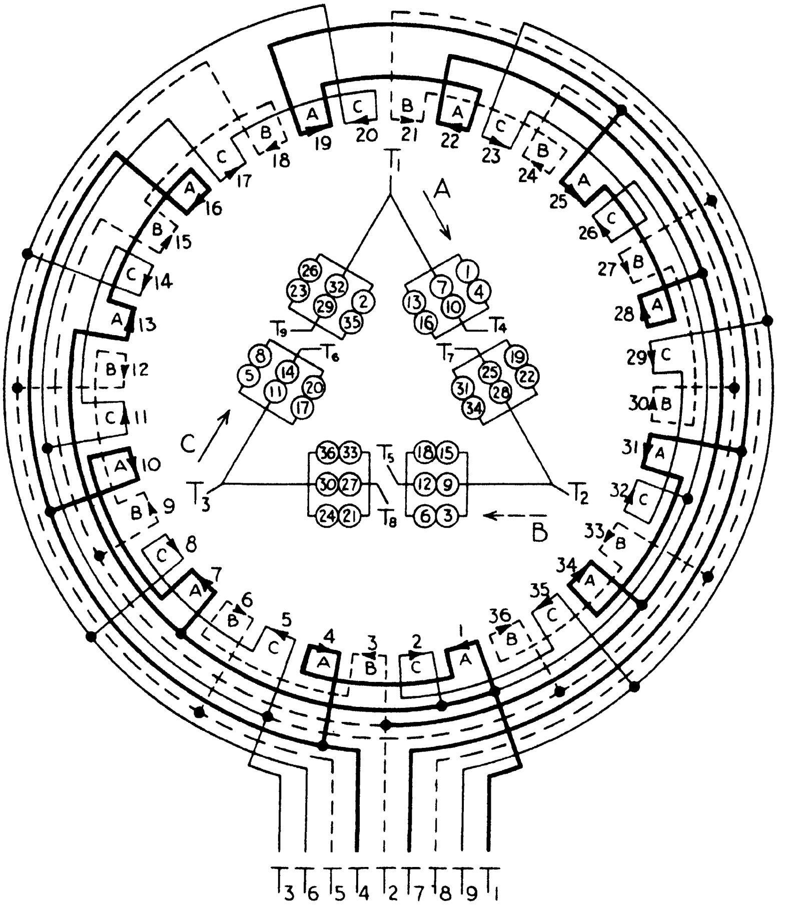


Fig. 3-109. 12-pole, 3-phase, 3- or 6-parallel delta connection diagram with 9 leads T-T

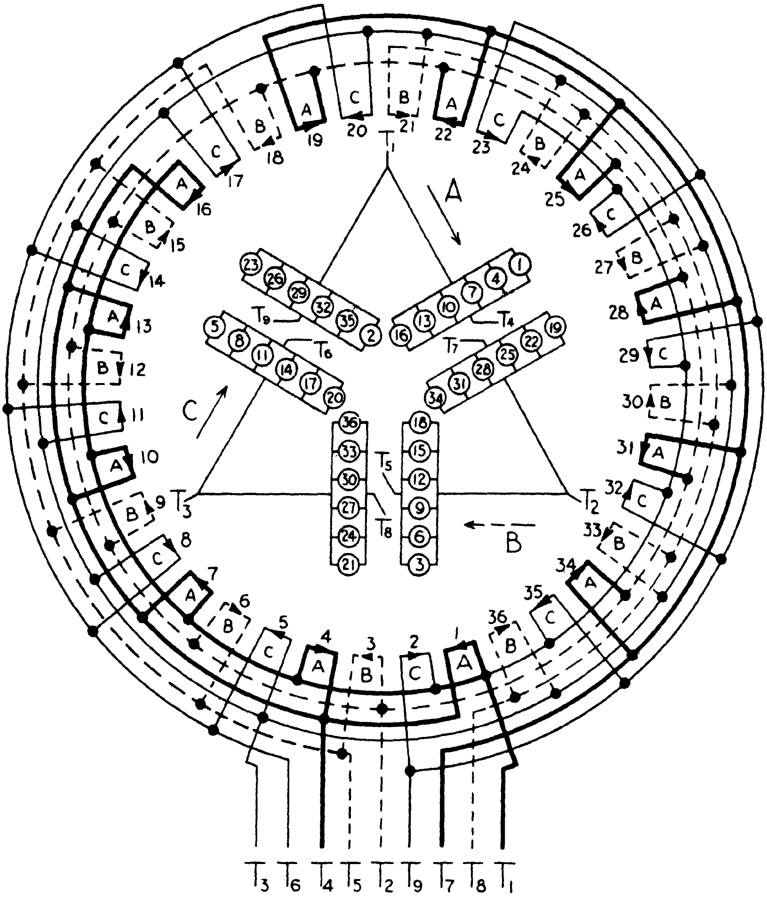


Fig. 3-110. 12-pole, 3-phase, 6- or 12-parallel delta connection diagram with 9 leads

TABLE 3-15

12-POLE 3-PHASE T-T CONNECTION TABLE

(Reference Connection Diagrams Figs. 3-91, 3-92, 3-93, 3-94, 3-95, 3-96, 3-101, 3-102, 3-103, 3-104, 3-105, 3-106)

Phase		Connections	Leads
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34	T_1 → S1 T_4 → S34
	2-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16‖S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34	T_1 → S1→S19 T_4 → S16→S34
	3-parallel	S1 F1→F4 S4→S7 F7→F10 S10‖S13 F13→F16 S16→S19 F19→F22 S22‖S25 F25→F28 S28→S31 F31→F34 S34	T_1 → S1→S13→S25 T_4 → S10→S22→S34
	4-parallel	S1 F1→F4 S4→S7 F7‖F10 S10→S13 F13→F16 S16‖S19 F19→F22 S22→S25 F25‖F28 S28→S31 F31→F34 S34	T_1 → S1→F10→S19→F28 T_4 → F7→S16→F25→S34
	6-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22‖S25 F25→F28 S28‖S31 F31→F34 S34	T_1 → S1→S7→S13→S19→S25→S31 T_4 → S4→S10→S16→S22→S28→S34
	12-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22‖S25 F25‖F28 S28‖S31 F31‖F34 S34	T_1 → S1→F4→S7→F10→S13→F16→S19→F22→S25→F28→S31→F34 T_4 → F1→S4→F7→S10→F13→S16→F19→S22→F25→S28→F31→S34
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36	T_2 → S3 T_5 → S36
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18‖S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36	T_2 → S3→S21 T_5 → S18→S36
	3-parallel	S3 F3→F6 S6→S9 F9→F12 S12‖S15 F15→F18 S18→S21 F21→F24 S24‖S27 F27→F30 S30→S33 F33→F36 S36	T_2 → S3→S15→S27 T_5 → S12→S24→S36
	4-parallel	S3 F3→F6 S6→S9 F9‖F12 S12→S15 F15→F18 S18‖S21 F21→F24 S24→S27 F27‖F30 S30→S33 F33→F36 S36	T_2 → S3→F12→S21→F30 T_5 → F9→S18→F27→S36
	6-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24‖S27 F27→F30 S30‖S33 F33→F36 S36	T_2 → S3→S9→S15→S21→S27→S33 T_5 → S6→S12→S18→S24→S30→S36
	12-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24‖S27 F27‖F30 S30‖S33 F33‖F36 S36	T_2 → S3→F6→S9→F12→S15→F18→S21→F24→S27→F30→S33→F36 T_5 → F3→S6→F9→S12→F15→S18→F21→S24→F27→S30→F33→S36
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F2 S2	T_3 → S5 T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20‖S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F2 S2	T_3 → S5→S23 T_6 → S20→S2
	3-parallel	S5 F5→F8 S8→S11 F11→F14 S14‖S17 F17→F20 S20→S23 F23→F26 S26‖S29 F29→F32 S32→S35 F35→F2 S2	T_3 → S5→S17→S29 T_6 → S14→S26→S2
	4-parallel	S5 F5→F8 S8→S11 F11‖F14 S14→S17 F17→F20 S20‖S23 F23→F26 S26→S29 F29‖F32 S32→S35 F35→F2 S2	T_3 → S5→F14→S23→F32 T_6 → F11→S20→F29→S2
	6-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F26 S26‖S29 F29→F32 S32‖S35 F35→F2 S2	T_3 → S5→S11→S17→S23→S29→S35 T_6 → S8→S14→S20→S26→S32→S2
	12-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F26 S26‖S29 F29‖F32 S32‖S35 F35‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F26→S29→F32→S35→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S26→F29→S32→F35→S2

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Δ Connection- T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

T-T = Top-to-top or bottom-to-bottom or short-jumper connection.

→ = connected to start or finish of a group.

‖ = spot for change with respect to series connection.

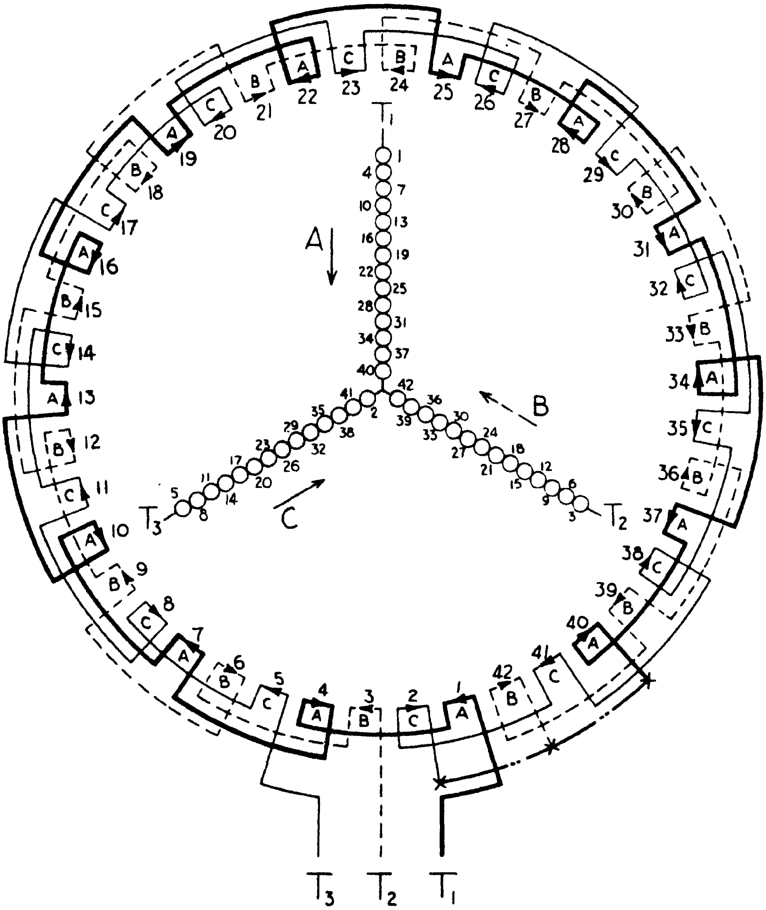


Fig. 3-111. 14-pole, 3-phase, series star connection diagram T-T

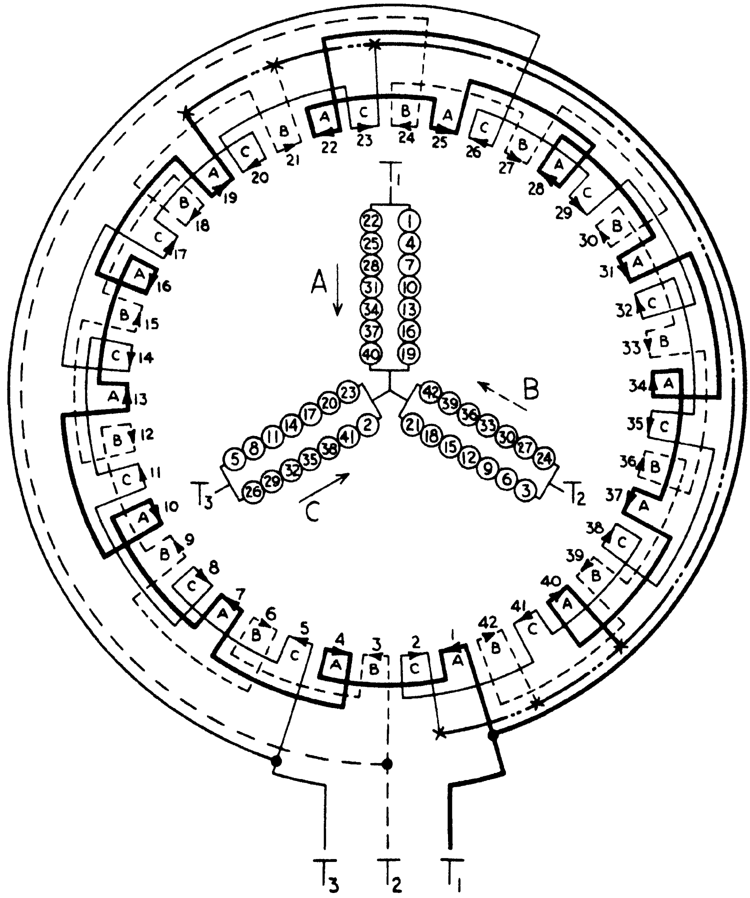


Fig. 3-112. 14-pole,3-phase,2-parallel star connection diagram T-T

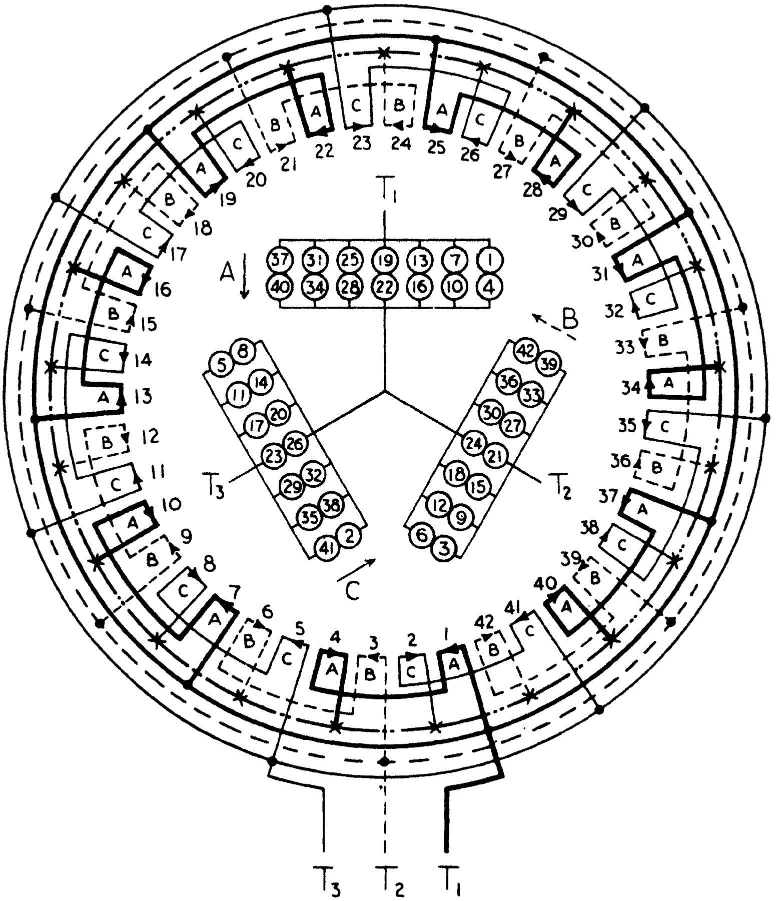


Fig. 3-113. 14-pole,3-phase,7-parallel star connection diagram T-T

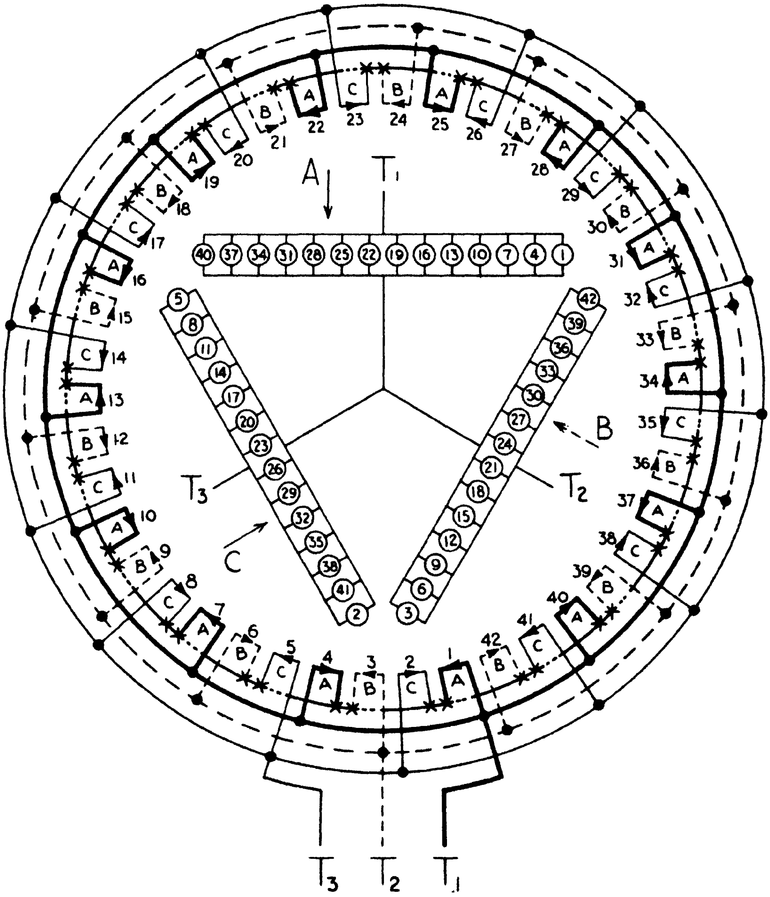


Fig. 3-114. 14-pole, 3-phase, 14-parallel star connection diagram

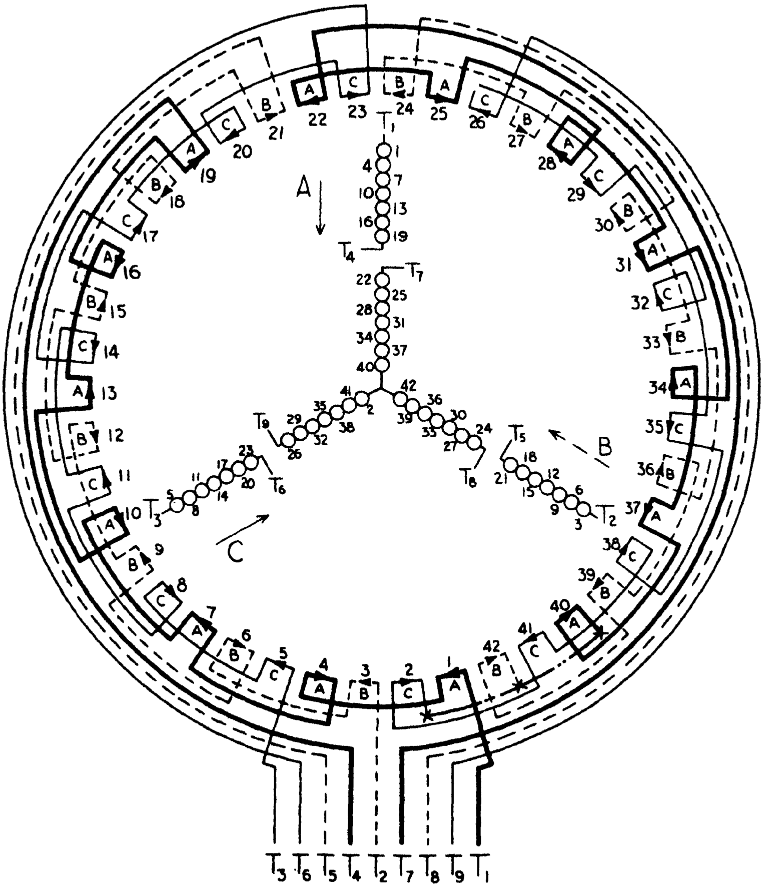


Fig. 3-115. 14-pole, 3-phase, series or 2-parallel star connection diagram with 9 leads T-T

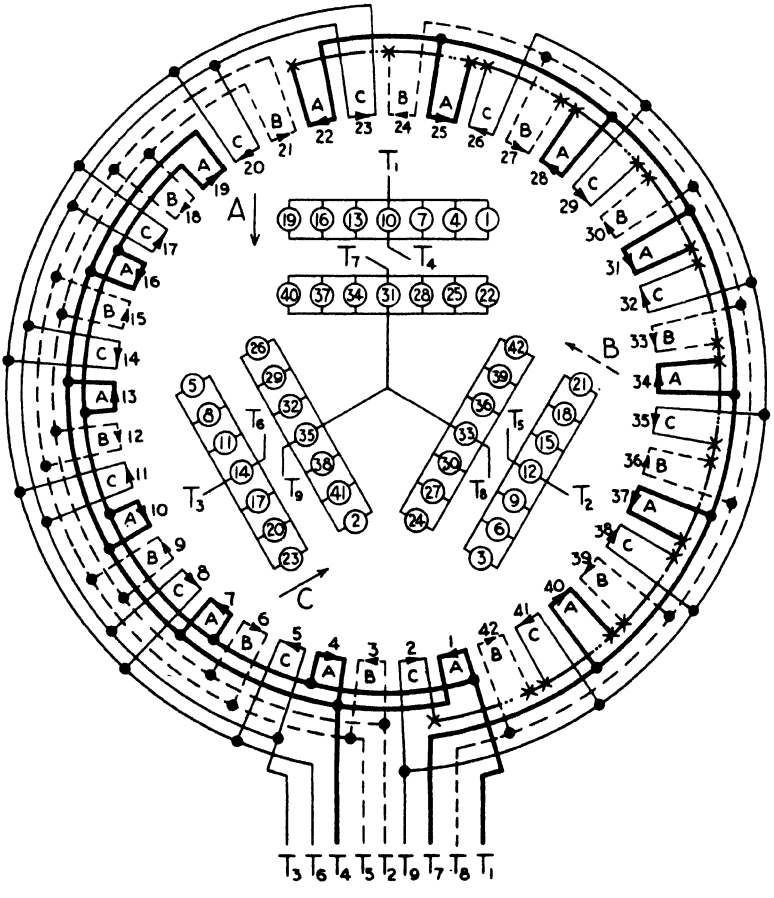


Fig. 3-116. 14-pole, 3-phase, 7- or 14-parallel star connection diagram with 9 leads

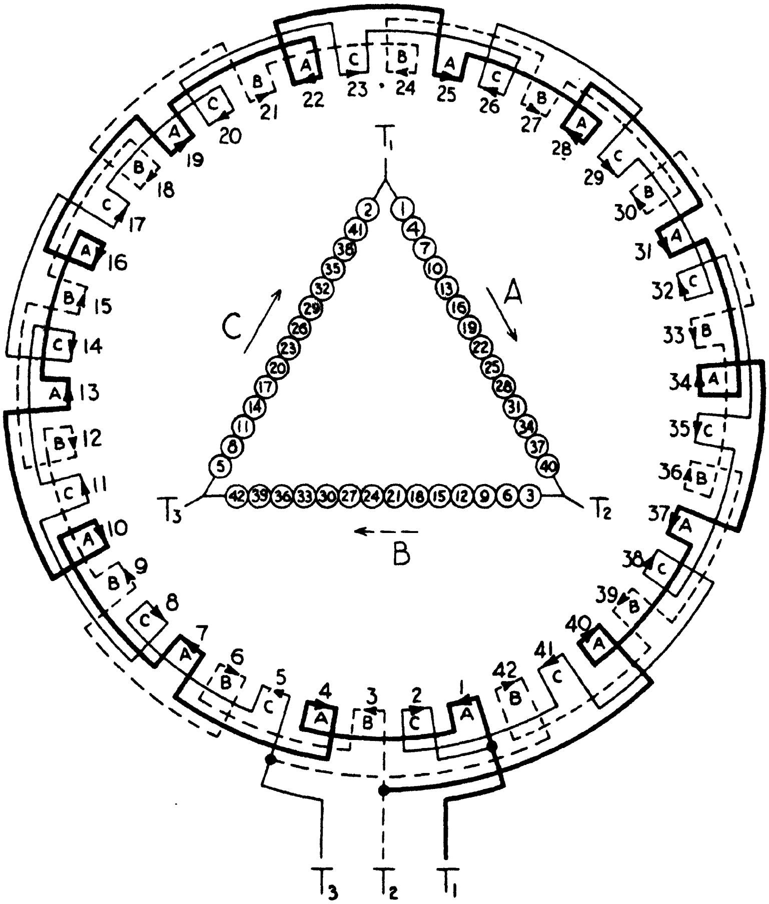


Fig. 3-117. 14-pole, 3-phase, series delta connection diagram T-T

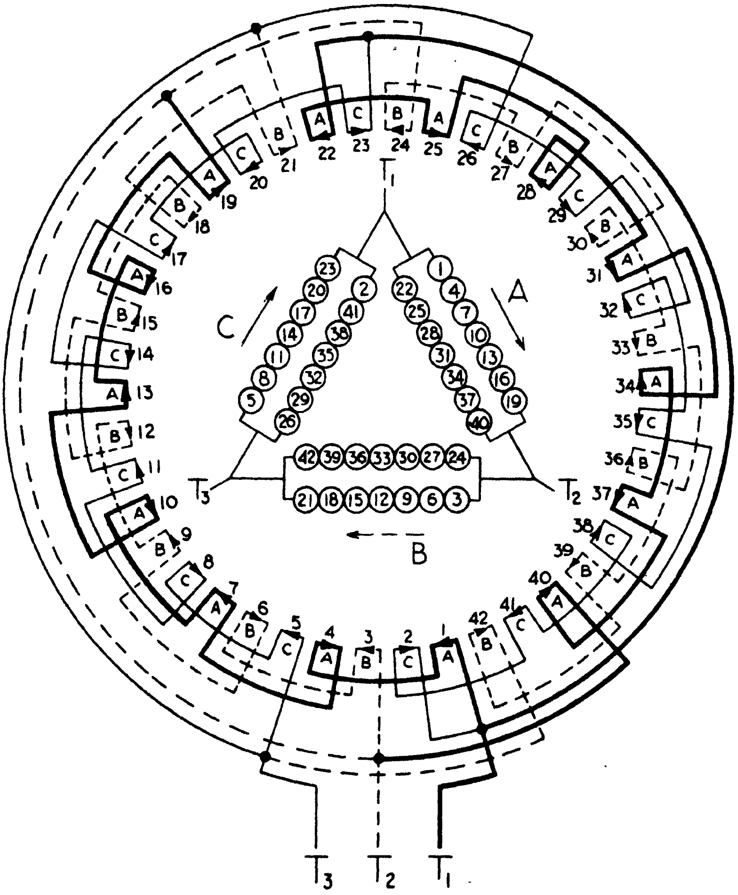


Fig. 3-118. 14-pole,3-phase,2-parallel delta connection diagram T-T

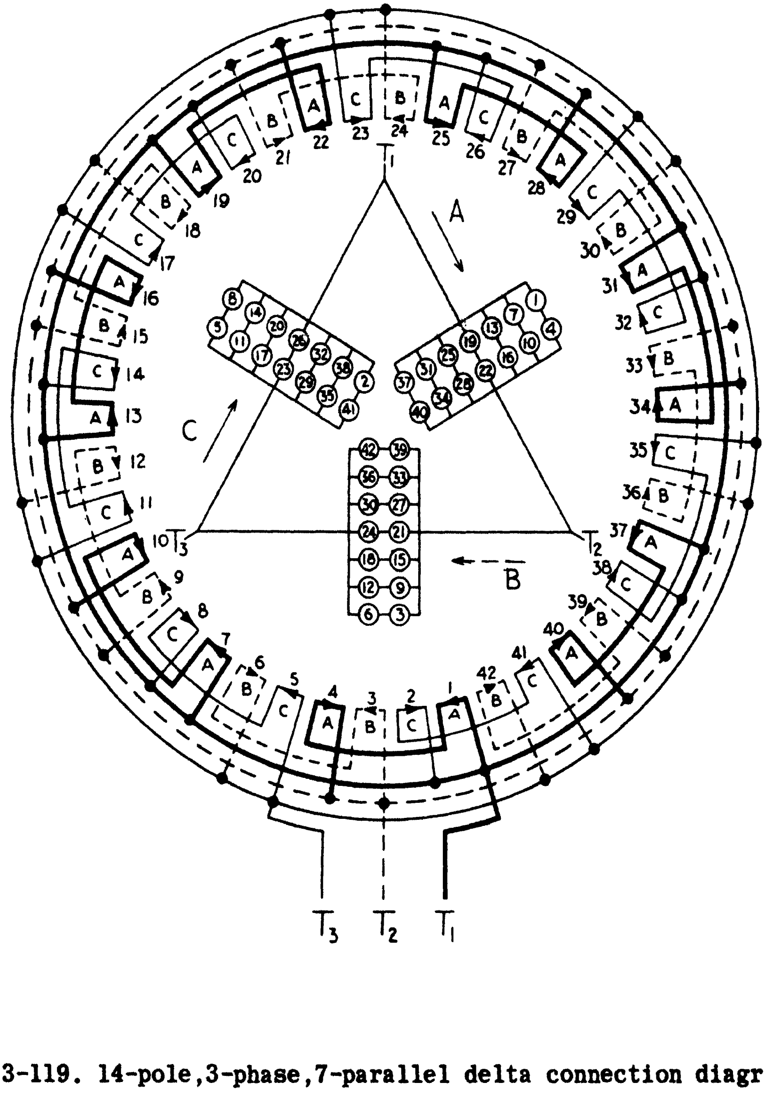


Fig. 3-119. 14-pole,3-phase,7-parallel delta connection diagram T-T

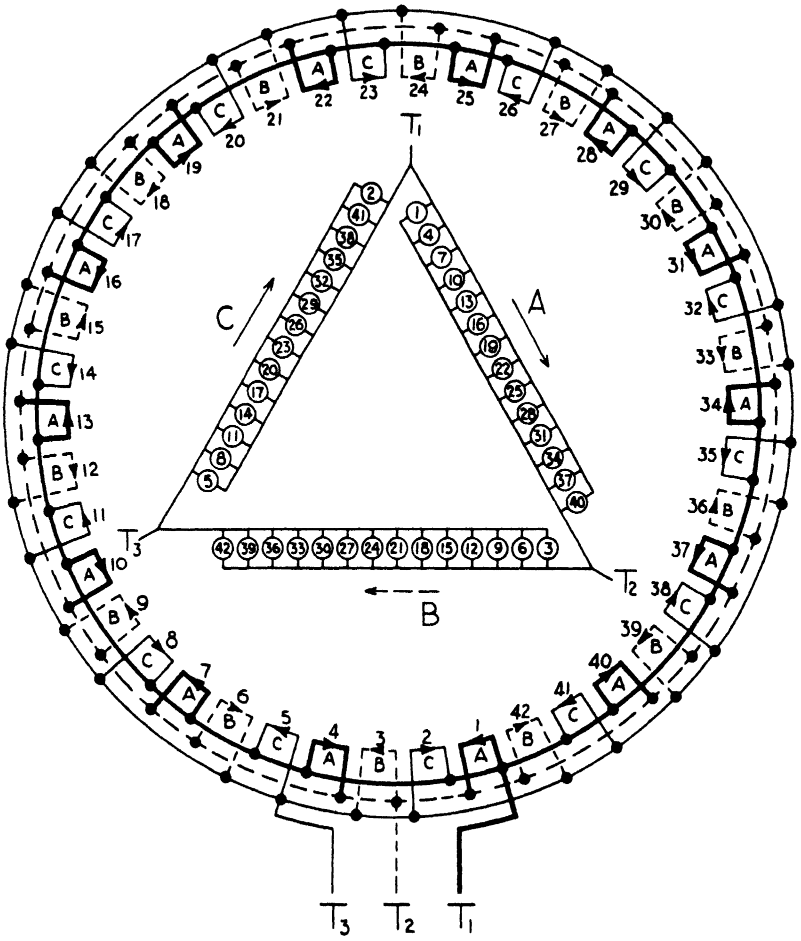


Fig. 3-120. 14-pole,3-phase,14-parallel delta connection diagram

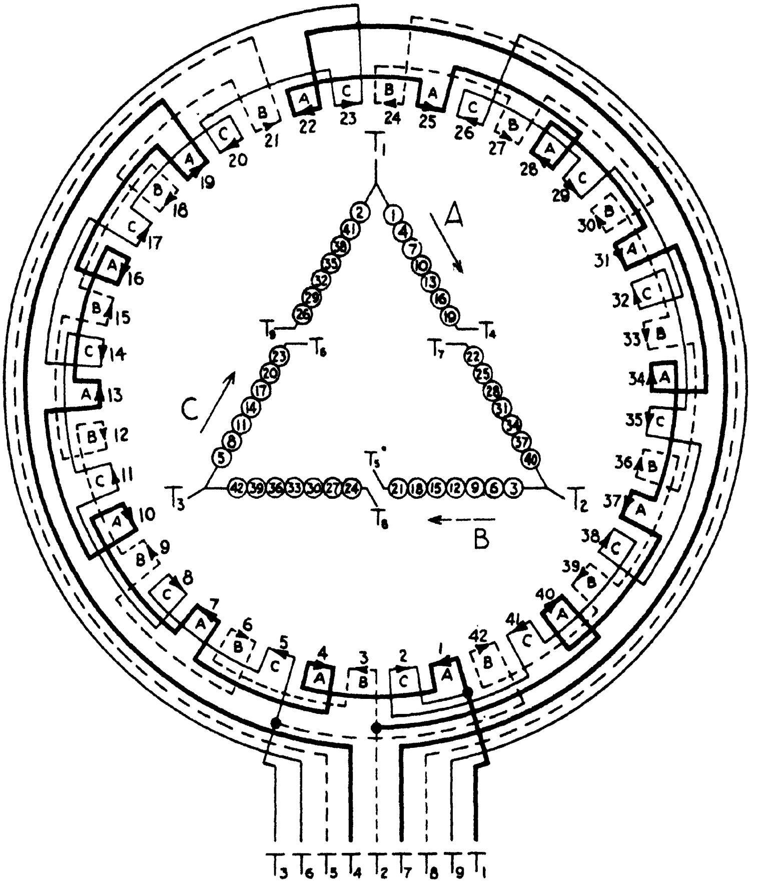


Fig. 3-121. 14-pole, 3-phase, series or 2-parallel delta connection diagram with 9 leads T-T

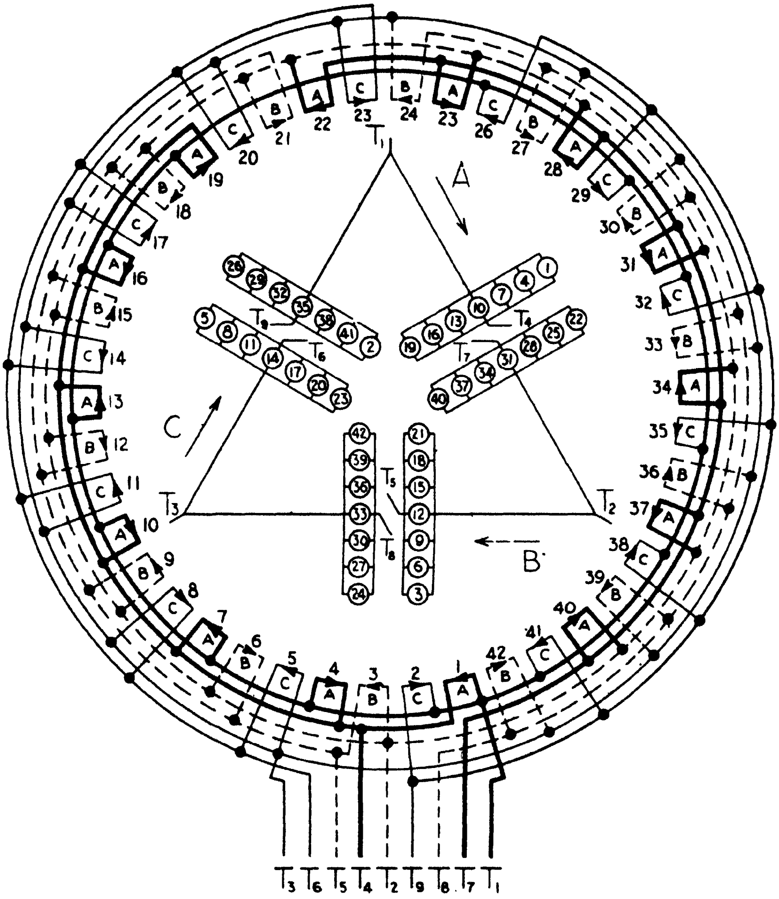


Fig. 3-122. 14-pole, 3-phase, 7- or 14-parallel delta connection diagram with 9 leads

TABLE 3-16

14-POLE 3-PHASE T-T CONNECTION TABLE

(Reference Connection Diagrams Figs. 3-111, 3-112, 3-113, 3-114, 3-117, 3-118, 3-119, 3-120)

Phase	Connections		Leads
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40	T_1 → S1 T_4 → S40
	2-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19‖F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40	T_1 → S1→F22 T_4 → F19→S40
	7-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22‖S25 F25→F28 S28‖S31 F31→F34 S34‖S37 F37→F40 S40	T_1 → S1→S7→S13→S19→S25→S31→S37 T_4 → S4→S10→S16→S22→S28→S34→S40
	14-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22‖S25 F25‖F28 S28‖S31 F31‖F34 S34‖S37 F37‖F40 S40	T_1 → S1→F4→S7→F10→S13→F16→S19→F22→S25→F28→S31→F34→S37→F40 T_4 → F1→S4→F7→S10→F13→S16→F19→S22→F25→S28→F31→S34→F37→S40
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42	T_2 → S3 T_5 → S42
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21‖F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42	T_2 → S3→F24 T_5 → F21→S42
	7-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24‖S27 F27→F30 S30‖S33 F33→F36 S36‖S39 F39→F42 S42	T_2 → S3→S9→S15→S21→S27→S33→S39 T_5 → S6→S12→S18→S24→S30→S36→S42
	14-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24‖S27 F27‖F30 S30‖S33 F33‖F36 S36‖S39 F39‖F42 S42	T_2 → S3→F6→S9→F12→S15→F18→S21→F24→S27→F30→S33→F36→S39→F42 T_5 → F3→S6→F9→S12→F15→S18→F21→S24→F27→S30→F33→S36→F39→S42
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F2 S2	T_3 → S5 T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23‖F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F2 S2	T_3 → S5→F26 T_6 → F23→S2
	7-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F26 S26‖S29 F29→F32 S32‖S35 F35→F38 S38‖S41 F41→F2 S2	T_3 → S5→S11→S17→S23→S29→S35→S41 T_6 → S8→S14→S20→S26→S32→S38→S2
	14-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F26 S26‖S29 F29‖F32 S32‖S35 F35‖F38 S38‖S41 F41‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F26→S29→F32→S35→F38→S41→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S26→F29→S32→F35→S38→F41→S2

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Δ Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.
F = finish of a group.
T-T = Top-to-top or bottom-to-bottom or short-jumper connection.
→ = connected to start or finish of a group.
‖ = spot for change with respect to series connection.

TABLE 3-17

16-POLE 3-PHASE T-T CONNECTION TABLE

Phase		Connections	Leads
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46	T_1 → S1 T_4 → S46
	2-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22‖S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46	T_1 → S1→S25 T_4 → S22→S46
	4-parallel	S1 F1→F4 S4→S7 F7→F10 S10‖S13 F13→F16 S16→S19 F19→F22 S22‖S25 F25→F28 S28→S31 F31→F34 S34‖S37 F37→F40 S40→S43 F43→F46 S46	T_1 → S1→S13→S25→S37 T_4 → S10→S22→S34→S46
	8-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22‖S25 F25→F28 S28‖S31 F31→F34 S34‖S37 F37→F40 S40‖S43 F43→F46 S46	T_1 → S1→S7→S13→S19→S25→S31→S37→S43 T_4 → S4→S10→S16→S22→S28→S34→S40→S46
	16-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22‖S25 F25‖F28 S28‖S31 F31‖F34 S34‖S37 F37‖F40 S40‖S43 F43‖F46 S46	T_1 → S1→F4→S7→F10→S13→F16→S19→F22→S25→F28→S31→F34→S37→F40→S43→F46 T_4 → F1→S4→F7→S10→F13→S16→F19→S22→F25→S28→F31→S34→F37→S40→F43→S46
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48	T_2 → S3 T_5 → S48
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24‖S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48	T_2 → S3→S27 T_5 → S24→S48
	4-parallel	S3 F3→F6 S6→S9 F9→F12 S12‖S15 F15→F18 S18→S21 F21→F24 S24‖S27 F27→F30 S30→S33 F33→F36 S36‖S39 F39→F42 S42→S45 F45→F48 S48	T_2 → S3→S15→S27→S39 T_5 → S12→S24→S36→S48
	8-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24‖S27 F27→F30 S30‖S33 F33→F36 S36‖S39 F39→F42 S42‖S45 F45→F48 S48	T_2 → S3→S9→S15→S21→S27→S33→S39→S45 T_5 → S6→S12→S18→S24→S30→S36→S42→S48
	16-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24‖S27 F27‖F30 S30‖S33 F33‖F36 S36‖S39 F39‖F42 S42‖S45 F45‖F48 S48	T_2 → S3→F6→S9→F12→S15→F18→S21→F24→S27→F30→S33→F36→S39→F42→S45→F48 T_5 → F3→S6→F9→S12→F15→S18→F21→S24→F27→S30→F33→S36→F39→S42→F45→S48
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F2 S2	T_3 → S5 T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26‖S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F2 S2	T_3 → S5→S29 T_6 → S26→S2
	4-parallel	S5 F5→F8 S8→S11 F11→F14 S14‖S17 F17→F20 S20→S23 F23→F26 S26‖S29 F29→F32 S32→S35 F35→F38 S38‖S41 F41→F44 S44→S47 F47→F2 S2	T_3 → S5→S17→S29→S41 T_6 → S14→S26→S38→S2
	8-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F26 S26‖S29 F29→F32 S32‖S35 F35→F38 S38‖S41 F41→F44 S44‖S47 F47→F2 S2	T_3 → S5→S11→S17→S23→S29→S35→S41→S47 T_6 → S8→S14→S20→S26→S32→S38→S44→S2
	16-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F26 S26‖S29 F29‖F32 S32‖S35 F35‖F38 S38‖S41 F41‖F44 S44‖S47 F47‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F26→S29→F32→S35→F38→S41→F44→S47→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S26→F29→S32→F35→S38→F41→S44→F47→S2

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Δ Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

→ = connected to start or finish of a group.

‖ = spot for change with respect to series connection.

T-T = Top-to-top or bottom-to-bottom or short-jumper connection.

TABLE 3-18

18-POLE 3-PHASE T-T CONNECTION TABLE

Phase	Connections		Leads	
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52	T_1 → S1	T_4 → S52
	2-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25‖F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52	T_1 → S1→F28	T_4 → F25→S52
	3-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16‖S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34‖S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52	T_1 → S1→S19→S37	T_4 → S16→S34→S52
	6-parallel	S1 F1→F4 S4→S7 F7‖F10 S10→S13 F13→F16 S16‖S19 F19→F22 S22→S25 F25‖F28 S28→S31 F31→F34 S34‖S37 F37→F40 S40→S43 F43‖F46 S46→S49 F49→F52 S52	T_1 → S1→F10→S19→F28→S37→F46	T_4 → F7→S16→F25→S34→F43→S52
	9-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22‖S25 F25→F28 S28‖S31 F31→F34 S34‖S37 F37→F40 S40‖S43 F43→F46 S46‖S49 F49→F52 S52	T_1 → S1→S7→S13→S19→S25→S31→S37→S43→S49 T_4 → S4→S10→S16→S22→S28→S34→S40→S46→S52	
	18-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22‖S25 F25‖F28 S28‖S31 F31‖F34 S34‖S37 F37‖F40 S40‖S43 F43‖F46 S46‖S49 F49‖F52 S52	T_1 → S1→F4→S7→F10→S13→F16→S19→F22→S25→F28→S31→F34→S37→F40→S43→F46→S49→F52 T_4 → F1→S4→F7→S10→F13→S16→F19→S22→F25→S28→F31→S34→F37→S40→F43→S46→F49→S52	
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54	T_2 → S3	T_5 → S54
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27‖F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54	T_2 → S3→F30	T_5 → F27→S54
	3-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18‖S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36‖S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54	T_2 → S3→S21→S39	T_5 → S18→S36→S54
	6-parallel	S3 F3→F6 S6→S9 F9‖F12 S12→S15 F15→F18 S18‖S21 F21→F24 S24→S27 F27‖F30 S30→S33 F33→F36 S36‖S39 F39→F42 S42→S45 F45‖F48 S48→S51 F51→F54 S54	T_2 → S3→F12→S21→F30→S39→F48	T_5 → F9→S18→F27→S36→F45→S54
	9-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24‖S27 F27→F30 S30‖S33 F33→F36 S36‖S39 F39→F42 S42‖S45 F45→F48 S48‖S51 F51→F54 S54	T_2 → S3→S9→S15→S21→S27→S33→S39→S45→S51 T_5 → S6→S12→S18→S24→S30→S36→S42→S48→S54	
	18-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24‖S27 F27‖F30 S30‖S33 F33‖F36 S36‖S39 F39‖F42 S42‖S45 F45‖F48 S48‖S51 F51‖F54 S54	T_2 → S3→F6→S9→F12→S15→F18→S21→F24→S27→F30→S33→F36→S39→F42→S45→F48→S51→F54 T_5 → F3→S6→F9→S12→F15→S18→F21→S24→F27→S30→F33→S36→F39→S42→F45→S48→F51→S54	
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F2 S2	T_3 → S5	T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29‖F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F2 S2	T_3 → S5→F32	T_6 → F29→S2
	3-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20‖S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38‖S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F2 S2	T_3 → S5→S23→S41	T_6 → S20→S38→S2
	6-parallel	S5 F5→F8 S8→S11 F11‖F14 S14→S17 F17→F20 S20‖S23 F23→F26 S26→S29 F29‖F32 S32→S35 F35→F38 S38‖S41 F41→F44 S44→S47 F47‖F50 S50→S53 F53→F2 S2	T_3 → S5→F14→S23→F32→S41→F50	T_6 → F11→S20→F29→S38→F47→S2
	9-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F26 S26‖S29 F29→F32 S32‖S35 F35→F38 S38‖S41 F41→F44 S44‖S47 F47→F50 S50‖S53 F53→F2 S2	T_3 → S5→S11→S17→S23→S29→S35→S41→S47→S53 T_6 → S8→S14→S20→S26→S32→S38→S44→S50→S2	
	18-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F26 S26‖S29 F29‖F32 S32‖S35 F35‖F38 S38‖S41 F41‖F44 S44‖S47 F47‖F50 S50‖S53 F53‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F26→S29→F32→S35→F38→S41→F44→S47→F50→S53→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S26→F29→S32→F35→S38→F41→S44→F47→S50→F53→S2	

Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

-T = Top-to-top or bottom-to-bottom or short-jumper connection.

→ = connected to start or finish of a group.

‖ = spot for change with respect to series connection

TABLE 3-19

20-POLE 3-PHASE T-T CONNECTION TABLE

hase		Connections	Leads
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58	T_1 → S1 T_4 → S58
	2-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28‖S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58	T_1 → S1→S31 T_4 → S28→S58
	4-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13‖F16 S16→S19 F19→F22 S22→S25 F25→F28 S28‖S31 F31→F34 S34→S37 F37→F40 S40→S43 F43‖F46 S46→S49 F49→F52 S52→S55 F55→F58 S58	T_1 → S1→F16→S31→F46 T_4 → F13→S28→F43→S58
	5-parallel	S1 F1→F4 S4→S7 F7→F10 S10‖S13 F13→F16 S16→S19 F19→F22 S22‖S25 F25→F28 S28→S31 F31→F34 S34‖S37 F37→F40 S40→S43 F43→F46 S46‖S49 F49→F52 S52→S55 F55→F58 S58	T_1 → S1→S13→S25→S37→S49 T_4 → S10→S22→S34→S46→S58
	10-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22‖S25 F25→F28 S28‖S31 F31→F34 S34‖S37 F37→F40 S40‖S43 F43→F46 S46‖S49 F49→F52 S52‖S55 F55→F58 S58	T_1 → S1→S7→S13→S19→S25→S31→S37→S43→S49→S55 T_4 → S4→S10→S16→S22→S28→S34→S40→S46→S52→S58
	20-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22‖S25 F25‖F28 S28‖S31 F31‖F34 S34‖S37 F37‖F40 S40‖S43 F43‖F46 S46‖S49 F49‖F52 S52‖S55 F55‖F58 S58	T_1 → S1→F4→S7→F10→S13→F16→S19→F22→S25→F28→S31→ F34→S37→F40→S43→F46→S49→F52→S55→F58 T_4 → F1→S4→F7→S10→F13→S16→F19→S22→F25→S28→F31→ S34→F37→S40→F43→S46→F49→S52→F55→S58
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60	T_2 → S3 T_5 → S60
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30‖S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60	T_2 → S3→S33 T_5 → S30→S60
	4-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15‖F18 S18→S21 F21→F24 S24→S27 F27→F30 S30‖S33 F33→F36 S36→S39 F39→F42 S42→S45 F45‖F48 S48→S51 F51→F54 S54→S57 F57→F60 S60	T_2 → S3→F18→S33→F48 T_5 → F15→S30→F45→S60
	5-parallel	S3 F3→F6 S6→S9 F9→F12 S12‖S15 F15→F18 S18→S21 F21→F24 S24‖S27 F27→F30 S30→S33 F33→F36 S36‖S39 F39→F42 S42→S45 F45→F48 S48‖S51 F51→F54 S54→S57 F57→F60 S60	T_2 → S3→S15→S27→S39→S51 T_5 → S12→S24→S36→S48→S60
	10-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24‖S27 F27→F30 S30‖S33 F33→F36 S36‖S39 F39→F42 S42‖S45 F45→F48 S48‖S51 F51→F54 S54‖S57 F57→F60 S60	T_2 → S3→S9→S15→S21→S27→S33→S39→S45→S51→S57 T_5 → S6→S12→S18→S24→S30→S36→S42→S48→S54→S60
	20-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24‖S27 F27‖F30 S30‖S33 F33‖F36 S36‖S39 F39‖F42 S42‖S45 F45‖F48 S48‖S51 F51‖F54 S54‖S57 F57‖F60 S60	T_2 → S3→F6→S9→F12→S15→F18→S21→F24→S27→F30→S33→ F36→S39→F42→S45→F48→S51→F54→S57→F60 T_5 → F3→S6→F9→S12→F15→S18→F21→S24→F27→S30→F33→ S36→F39→S42→F45→S48→F51→S54→F57→S60
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F2 S2	T_3 → S5 T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32‖S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F2 S2	T_3 → S5→S35 T_6 → S32→S2
	4-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17‖F20 S20→S23 F23→F26 S26→S29 F29→F32 S32‖S35 F35→F38 S38→S41 F41→F44 S44→S47 F47‖F50 S50→S53 F53→F56 S56→S59 F59→F2 S2	T_3 → S5→F20→S35→F50 T_6 → F17→S32→F47→S2
	5-parallel	S5 F5→F8 S8→S11 F11→F14 S14‖S17 F17→F20 S20→S23 F23→F26 S26‖S29 F29→F32 S32→S35 F35→F38 S38‖S41 F41→F44 S44→S47 F47→F50 S50‖S53 F53→F56 S56→S59 F59→F2 S2	T_3 → S5→S17→S29→S41→S53 T_6 → S14→S26→S38→S50→S2
	10-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F26 S26‖S29 F29→F32 S32‖S35 F35→F38 S38‖S41 F41→F44 S44‖S47 F47→F50 S50‖S53 F53→F56 S56‖S59 F59→F2 S2	T_3 → S5→S11→S17→S23→S29→S35→S41→S47→S53→S59 T_6 → S8→S14→S20→S26→S32→S38→S44→S50→S56→S2
	20-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F26 S26‖S29 F29‖F32 S32‖S35 F35‖F38 S38‖S41 F41‖F44 S44‖S47 F47‖F50 S50‖S53 F53‖F56 S56‖S59 F59‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F26→S29→F32→S35→ F38→S41→F44→S47→F50→S53→F56→S59→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S26→F29→S32→F35→ S38→F41→S44→F47→S50→F53→S56→F59→S2

Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

-T = Top-to-top or bottom-to-bottom or short-jumper connection.

→ = connected to start or finish of a group.

| = spot for change with respect to series connection

TABLE 3-20

22-POLE 3-PHASE T-T CONNECTION TABLE

Phase		Connections	Leads
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58→S61 F61→F64 S64	T_1 → S1 T_4 → S64
	2-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31‖F34 S34→S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58→S61 F61→F64 S64	T_1 → S1→F34 T_4 → F31→S64
	11-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22‖S25 F25→F28 S28‖S31 F31→F34 S34‖S37 F37→F40 S40‖S43 F43→F46 S46‖S49 F49→F52 S52‖S55 F55→F58 S58‖S61 F61→F64 S64	T_1 → S1→S7→S13→S19→S25→S31→S37→S43→S49→S55→S61 T_4 → S4→S10→S16→S22→S28→S34→S40→S46→S52→S58→S64
	22-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22‖S25 F25‖F28 S28‖S31 F31‖F34 S34‖S37 F37‖F40 S40‖S43 F43‖F46 S46‖S49 F49‖F52 S52‖S55 F55‖F58 S58‖S61 F61‖F64 S64	T_1 → S1→F4→S7→F10→S13→F16→S19→F22→S25→F28→S31→ F34→S37→F40→S43→F46→S49→F52→S55→F58→S61→F64 T_4 → F1→S4→F7→S10→F13→S16→F19→S22→F25→S28→F31→ S34→F37→S40→F43→S46→F49→S52→F55→S58→F61→S64
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60→S63 F63→F66 S66	T_2 → S2 T_5 → S66
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33‖F36 S36→S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60→S63 F63→F66 S66	T_2 → S3→F36 T_5 → F33→S66
	11-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24‖S27 F27→F30 S30‖S33 F33→F36 S36‖S39 F39→F42 S42‖S45 F45→F48 S48‖S51 F51→F54 S54‖S57 F57→F60 S60‖S63 F63→F66 S66	T_2 → S3→S9→S15→S21→S27→S33→S39→S45→S51→S57→S63 T_5 → S6→S12→S18→S24→S30→S36→S42→S48→S54→S60→S66
	22-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24‖S27 F27‖F30 S30‖S33 F33‖F36 S36‖S39 F39‖F42 S42‖S45 F45‖F48 S48‖S51 F51‖F54 S54‖S57 F57‖F60 S60‖S63 F63‖F66 S66	T_2 → S3→F6→S9→F12→S15→F18→S21→F24→S27→F30→S33→ F36→S39→F42→S45→F48→S51→F54→S57→F60→S63→F66 T_5 → F3→S6→F9→S12→F15→S18→F21→S24→F27→S30→F33→ S36→F39→S42→F45→S48→F51→S54→F57→S60→F63→S66
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F62 S62→S65 F65→F2 S2	T_3 → S5 T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35‖F38 S38→S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F62 S62→S65 F65→F2 S2	T_3 → S5→F38 T_6 → F35→S2
	11-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F26 S26‖S29 F29→F32 S32‖S35 F35→F38 S38‖S41 F41→F44 S44‖S47 F47→F50 S50‖S53 F53→F56 S56‖S59 F59→F62 S62‖S65 F65→F2 S2	T_3 → S5→S11→S17→S23→S29→S35→S41→S47→S53→S59→S65 T_6 → S8→S14→S20→S26→S32→S38→S44→S50→S56→S62→S2
	22-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F26 S26‖S29 F29‖F32 S32‖S35 F35‖F38 S38‖S41 F41‖F44 S44‖S47 F47‖F50 S50‖S53 F53‖F56 S56‖S59 F59‖F62 S62‖S65 F65‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F26→S29→F32→S35→ F38→S41→F44→S47→F50→S53→F56→S59→F62→S65→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S26→F29→S32→F35→ S38→F41→S44→F47→S50→F53→S56→F59→S62→F65→S2

Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

-T = Top-to-top or bottom-to-bottom or short-jumper connection.

→ = connected to start or finish of a group.

‖ = spot for change with respect to series connection

TABLE 3-21

24-POLE 3-PHASE T-T CONNECTION TABLE

Phase	Connections		Leads
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58→S61 F61→F64 S64→S67 F67→F70 S70	T_1 → S1 T_4 → S70
	2-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34‖S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58→S61 F61→F64 S64→S67 F67→F70 S70	T_1 → S1→S37 T_4 → S34→S70
	3-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22‖S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46‖S49 F49→F52 S52→S55 F55→F58 S58→S61 F61→F64 S64→S67 F67→F70 S70	T_1 → S1→S25→S49 T_4 → S22→S46→S70
	4-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16‖S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34‖S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52‖S55 F55→F58 S58→S61 F61→F64 S64→S67 F67→F70 S70	T_1 → S1→S19→S37→S55 T_4 → S16→S34→S52→S70
	6-parallel	S1 F1→F4 S4→S7 F7→F10 S10‖S13 F13→F16 S16→S19 F19→F22 S22‖S25 F25→F28 S28→S31 F31→F34 S34‖S37 F37→F40 S40→S43 F43→F46 S46‖S49 F49→F52 S52→S55 F55→F58 S58‖S61 F61→F64 S64→S67 F67→F70 S70	T_1 → S1→S13→S25→S37→S49→S61 T_4 → S10→S22→S34→S46→S58→S70
	8-parallel	S1 F1→F4 S4→S7 F7‖F10 S10→S13 F13→F16 S16‖S19 F19→F22 S22→S25 F25‖F28 S28→S31 F31→F34 S34‖S37 F37→F40 S40→S43 F43‖F46 S46→S49 F49→F52 S52‖S55 F55→F58 S58→S61 F61‖F64 S64→S67 F67→F70 S70	T_1 → S1→F10→S19→F28→S37→F46→S55→F64 T_4 → F7→S16→F25→S34→F43→S52→F61→S70
	12-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22‖S25 F25→F28 S28‖S31 F31→F34 S34‖S37 F37→F40 S40‖S43 F43→F46 S46‖S49 F49→F52 S52‖S55 F55→F58 S58‖S61 F61→F64 S64‖S67 F67→F70 S70	T_1 → S1→S7→S13→S19→S25→S31→S37→S43→S49→S55→S61→S67 T_4 → S4→S10→S16→S22→S28→S34→S40→S46→S52→S58→S64→S70
	24-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22‖S25 F25‖F28 S28‖S31 F31‖F34 S34‖S37 F37‖F40 S40‖S43 F43‖F46 S46‖S49 F49‖F52 S52‖S55 F55‖F58 S58‖S61 F61‖F64 S64‖S67 F67‖F70 S70	T_1 → S1→F4→S7→F10→S13→F16→S19→F22→S25→F28→S31→F34→S37→F40→S43→F46→S49→F52→S55→F58→S61→F64→S67→F70 T_4 → F1→S4→F7→S10→F13→S16→F19→S22→F25→S28→F31→S34→F37→S40→F43→S46→F49→S52→F55→S58→F61→S64→F67→S70
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60→S63 F63→F66 S66→S69 F69→F72 S72	T_2 → S3 T_5 → S72
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36‖S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60→S63 F63→F66 S66→S69 F69→F72 S72	T_2 → S3→S39 T_5 → S36→S72
	3-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24‖S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48‖S51 F51→F54 S54→S57 F57→F60 S60→S63 F63→F66 S66→S69 F69→F72 S72	T_2 → S3→S27→S51 T_5 → S24→S48→S72
	4-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18‖S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36‖S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54‖S57 F57→F60 S60→S63 F63→F66 S66→S69 F69→F72 S72	T_2 → S3→S21→S39→S57 T_5 → S18→S36→S54→S72
	6-parallel	S3 F3→F6 S6→S9 F9→F12 S12‖S15 F15→F18 S18→S21 F21→F24 S24‖S27 F27→F30 S30→S33 F33→F36 S36‖S39 F39→F42 S42→S45 F45→F48 S48‖S51 F51→F54 S54→S57 F57→F60 S60‖S63 F63→F66 S66→S69 F69→F72 S72	T_2 → S3→S15→S27→S39→S51→S63 T_5 → S12→S24→S36→S48→S60→S72
	8-parallel	S3 F3→F6 S6→S9 F9‖F12 S12→S15 F15→F18 S18‖S21 F21→F24 S24→S27 F27‖F30 S30→S33 F33→F36 S36‖S39 F39→F42 S42→S45 F45‖F48 S48→S51 F51→F54 S54‖S57 F57→F60 S60→S63 F63‖F66 S66→S69 F69→F72 S72	T_2 → S3→F12→S21→F30→S39→F48→S57→F66 T_5 → F9→S18→F27→S36→F45→S54→F63→S72
	12-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24‖S27 F27→F30 S30‖S33 F33→F36 S36‖S39 F39→F42 S42‖S45 F45→F48 S48‖S51 F51→F54 S54‖S57 F57→F60 S60‖S63 F63→F66 S66‖S69 F69→F72 S72	T_2 → S3→S9→S15→S21→S27→S33→S39→S45→S51→S57→S63→S69 T_5 → S6→S12→S18→S24→S30→S36→S42→S48→S54→S60→S66→S72
	24-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24‖S27 F27‖F30 S30‖S33 F33‖F36 S36‖S39 F39‖F42 S42‖S45 F45‖F48 S48‖S51 F51‖F54 S54‖S57 F57‖F60 S60‖S63 F63‖F66 S66‖S69 F69‖F72 S72	T_2 → S3→F6→S9→F12→S15→F18→S21→F24→S27→F30→S33→F36→S39→F42→S45→F48→S51→F54→S57→F60→S63→F66→S69→F72 T_5 → F3→S6→F9→S12→F15→S18→F21→S24→F27→S30→F33→S36→F39→S42→F45→S48→F51→S54→F57→S60→F63→S66→F69→S72
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F62 S62→S65 F65→F68 S68→S71 F71→F2 S2	T_3 → S5 T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38‖S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F62 S62→S65 F65→F68 S68→S71 F71→F2 S2	T_3 → S5→S41 T_6 → S38→S2
	3-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26‖S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F50 S50‖S53 F53→F56 S56→S59 F59→F62 S62→S65 F65→F68 S68→S71 F71→F2 S2	T_3 → S5→S29→S53 T_6 → S26→S50→S2
	4-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20‖S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38‖S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56‖S59 F59→F62 S62→S65 F65→F68 S68→S71 F71→F2 S2	T_3 → S5→S23→S41→S59 T_6 → S20→S38→S56→S2
	6-parallel	S5 F5→F8 S8→S11 F11→F14 S14‖S17 F17→F20 S20→S23 F23→F26 S26‖S29 F29→F32 S32→S35 F35→F38 S38‖S41 F41→F44 S44→S47 F47→F50 S50‖S53 F53→F56 S56→S59 F59→F62 S62‖S65 F65→F68 S68→S71 F71→F2 S2	T_3 → S5→S17→S29→S41→S53→S65 T_6 → S14→S26→S38→S50→S62→S2
	8-parallel	S5 F5→F8 S8→S11 F11‖F14 S14→S17 F17→F20 S20‖S23 F23→F26 S26→S29 F29‖F32 S32→S35 F35→F38 S38‖S41 F41→F44 S44→S47 F47‖F50 S50→S53 F53→F56 S56‖S59 F59→F62 S62→S65 F65‖F68 S68→S71 F71→F2 S2	T_3 → S5→F14→S23→F32→S41→F50→S59→F68 T_6 → F11→S20→F29→S38→F47→S56→F65→S2
	12-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F26 S26‖S29 F29→F32 S32‖S35 F35→F38 S38‖S41 F41→F44 S44‖S47 F47→F50 S50‖S53 F53→F56 S56‖S59 F59→F62 S62‖S65 F65→F68 S68‖S71 F71→F2 S2	T_3 → S5→S11→S17→S23→S29→S35→S41→S47→S53→S59→S65→S71 T_6 → S8→S14→S20→S26→S32→S38→S44→S50→S56→S62→S68→S2
	24-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F26 S26‖S29 F29‖F32 S32‖S35 F35‖F38 S38‖S41 F41‖F44 S44‖S47 F47‖F50 S50‖S53 F53‖F56 S56‖S59 F59‖F62 S62‖S65 F65‖F68 S68‖S71 F71‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F26→S29→F32→S35→F38→S41→F44→S47→F50→S53→F56→S59→F62→S65→F68→S71→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S26→F29→S32→F35→S38→F41→S44→F47→S50→F53→S56→F59→S62→F65→S68→F71→S2

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Δ Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

T-T = Top-to-top or bottom-to-bottom or short-jumper connection.

→ = connected to start or finish of a group.

‖ = spot for change with respect to series connection.

TABLE 3-22

26-POLE 3-PHASE T-T CONNECTION TABLE

Phase	Connections		Leads
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58→S61 F61→F64 S64→S67 F67→F70 S70→S73 F73→F76 S76	T_1 → S1 T_4 → S76
	2-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37‖F40 S40→S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58→S61 F61→F64 S64→S67 F67→F70 S70→S73 F73→F76 S76	T_1 → S1→F40 T_4 → F37→S76
	13-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22‖S25 F25→F28 S28‖S31 F31→F34 S34‖S37 F37→F40 S40‖S43 F43→F46 S46‖S49 F49→F52 S52‖S55 F55→F58 S58‖S61 F61→F64 S64‖S67 F67→F70 S70‖S73 F73→F76 S76	T_1 → S1→S7→S13→S19→S25→S31→S37→S43→S49→S55→S61→S67→S73 T_4 → S4→S10→S16→S22→S28→S34→S40→S46→S52→S58→S64→S70→S76
	26-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22‖S25 F25‖F28 S28‖S31 F31‖F34 S34‖S37 F37‖F40 S40‖S43 F43‖F46 S46‖S49 F49‖F52 S52‖S55 F55‖F58 S58‖S61 F61‖F64 S64‖S67 F67‖F70 S70‖S73 F73‖F76 S76	T_1 → S1→F4→S7→F10→S13→F16→S19→F22→S25→F28→S31→F34→S37→F40→ S43→F46→S49→F52→S55→F58→S61→F64→S67→F70→S73→F76 T_4 → F1→S4→F7→S10→F13→S16→F19→S22→F25→S28→F31→S34→F37→S40→ F43→S46→F49→S52→F55→S58→F61→S64→F67→S70→F73→S76
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60→S63 F63→F66 S66→S69 F69→F72 S72→S75 F75→F78 S78	T_2 → S3 T_5 → S78
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39‖F42 S42→S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60→S63 F63→F66 S66→S69 F69→F72 S72→S75 F75→F78 S78	T_2 → S3→F42 T_5 → F39→S78
	13-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24‖S27 F27→F30 S30‖S33 F33→F36 S36‖S39 F39→F42 S42‖S45 F45→F48 S48‖S51 F51→F54 S54‖S57 F57→F60 S60‖S63 F63→F66 S66‖S69 F69→F72 S72‖S75 F75→F78 S78	T_2 → S3→S9→S15→S21→S27→S33→S39→S45→S51→S57→S63→S69→S75 T_5 → S6→S12→S18→S24→S30→S36→S42→S48→S54→S60→S66→S72→S78
	26-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24‖S27 F27‖F30 S30‖S33 F33‖F36 S36‖S39 F39‖F42 S42‖S45 F45‖F48 S48‖S51 F51‖F54 S54‖S57 F57‖F60 S60‖S63 F63‖F66 S66‖S69 F69‖F72 S72‖S75 F75‖F78 S78	T_2 → S3→F6→S9→F12→S15→F18→S21→F24→S27→F30→S33→F36→S39→F42→ S45→F48→S51→F54→S57→F60→S63→F66→S69→F72→S75→F78 T_5 → F3→S6→F9→S12→F15→S18→F21→S24→F27→S30→F33→S36→F39→S42→ F45→S48→F51→S54→F57→S60→F63→S66→F69→S72→F75→S78
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F62 S62→S65 F65→F68 S68→S71 F71→F74 S74→S77 F77→F2 S2	T_3 → S5 T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41‖F44 S44→S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F62 S62→S65 F65→F68 S68→S71 F71→F74 S74→S77 F77→F2 S2	T_3 → S5→F44 T_6 → F41→S2
	13-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F26 S26‖S29 F29→F32 S32‖S35 F35→F38 S38‖S41 F41→F44 S44‖S47 F47→F50 S50‖S53 F53→F56 S56‖S59 F59→F62 S62‖S65 F65→F68 S68‖S71 F71→F74 S74‖S77 F77→F2 S2	T_3 → S5→S11→S17→S23→S29→S35→S41→S47→S53→S59→S65→S71→S77 T_6 → S8→S14→S20→S26→S32→S38→S44→S50→S56→S62→S68→S74→S2
	26-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F26 S26‖S29 F29‖F32 S32‖S35 F35‖F38 S38‖S41 F41‖F44 S44‖S47 F47‖F50 S50‖S53 F53‖F56 S56‖S59 F59‖F62 S62‖S65 F65‖F68 S68‖S71 F71‖F74 S74‖S77 F77‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F26→S29→F32→S35→F38→S41→ →F44→S47→F50→S53→F56→S59→F62→S65→F68→S71→F74→S77→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S26→F29→S32→F35→S38→F41→ →S44→F47→S50→F53→S56→F59→S62→F65→S68→F71→S74→F77→S2

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Δ Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

T-T = Top-to-top or bottom-to-bottom or short-jumper connection.

→ = connected to start or finish of a group.

‖ = spot for change with respect to series connection.

TABLE 3-23

28-POLE 3-PHASE T-T CONNECTION TABLE

Phase	Connections		Leads
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58→S61 F61→F64 S64→S67 F67→F70 S70→S73 F73→F76 S76→S79 F79→F82 S82	T_1 → S1 T_4 → S82
	2-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40‖S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58→S61 F61→F64 S64→S67 F67→F70 S70→S73 F73→F76 S76→S79 F79→F82 S82	T_1 → S1→S43 T_4 → S40→S82
	4-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19‖F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40‖S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58→S61 F61‖F64 S64→S67 F67→F70 S70→S73 F73→F76 S76→S79 F79→F82 S82	T_1 → S1→F22→S43→F64 T_4 → F19→S40→F61→S82
	7-parallel	S1 F1→F4 S4→S7 F7→F10 S10‖S13 F13→F16 S16→S19 F19→F22 S22‖S25 F25→F28 S28→S31 F31→F34 S34‖S37 F37→F40 S40→S43 F43→F46 S46‖S49 F49→F52 S52→S55 F55→F58 S58‖S61 F61→F64 S64→S67 F67→F70 S70‖S73 F73→F76 S76→S79 F79→F82 S82	T_1 → S1→S13→S25→S37→S49→S61→S73 T_4 → S10→S22→S34→S46→S58→S70→S82
	14-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22‖S25 F25→F28 S28‖S31 F31→F34 S34‖S37 F37→F40 S40‖S43 F43→F46 S46‖S49 F49→F52 S52‖S55 F55→F58 S58‖S61 F61→F64 S64‖S67 F67→F70 S70‖S73 F73→F76 S76‖S79 F79→F82 S82	T_1 → S1→S7→S13→S19→S25→S31→S37→S43→S49→S55→S61→S67→S73→S79 T_4 → S4→S10→S16→S22→S28→S34→S40→S46→S52→S58→S64→S70→S76→S82
	28-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22‖S25 F25‖F28 S28‖S31 F31‖F34 S34‖S37 F37‖F40 S40‖S43 F43‖F46 S46‖S49 F49‖F52 S52‖S55 F55‖F58 S58‖S61 F61‖F64 S64‖S67 F67‖F70 S70‖S73 F73‖F76 S76‖S79 F79‖F82 S82	T_1 → S1→F4→S7→F10→S13→F16→S19→F22→S25→F28→S31→F34→S37→F40→ S43→F46→S49→F52→S55→F58→S61→F64→S67→F70→S73→F76→S79→F82 T_4 → F1→S4→F7→S10→F13→S16→F19→S22→F25→S28→F31→S34→F37→S40→ F43→S46→F49→S52→F55→S58→F61→S64→F67→S70→F73→S76→F79→S82
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60→S63 F63→F66 S66→S69 F69→F72 S72→S75 F75→F78 S78→S81 F81→F84 S84	T_2 → S3 T_5 → S84
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42‖S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60→S63 F63→F66 S66→S69 F69→F72 S72→S75 F75→F78 S78→S81 F81→F84 S84	T_2 → S3→S45 T_5 → S42→S84
	4-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21‖F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42‖S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60→S63 F63‖F66 S66→S69 F69→F72 S72→S75 F75→F78 S78→S81 F81→F84 S84	T_2 → S3→F24→S45→F66 T_5 → F21→S42→F63→S84
	7-parallel	S3 F3→F6 S6→S9 F9→F12 S12‖S15 F15→F18 S18→S21 F21→F24 S24‖S27 F27→F30 S30→S33 F33→F36 S36‖S39 F39→F42 S42→S45 F45→F48 S48‖S51 F51→F54 S54→S57 F57→F60 S60‖S63 F63→F66 S66→S69 F69→F72 S72‖S75 F75→F78 S78→S81 F81→F84 S84	T_2 → S3→S15→S27→S39→S51→S63→S75 T_5 → S12→S24→S36→S48→S60→S72→S84
	14-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24‖S27 F27→F30 S30‖S33 F33→F36 S36‖S39 F39→F42 S42‖S45 F45→F48 S48‖S51 F51→F54 S54‖S57 F57→F60 S60‖S63 F63→F66 S66‖S69 F69→F72 S72‖S75 F75→F78 S78‖S81 F81→F84 S84	T_2 → S3→S9→S15→S21→S27→S33→S39→S45→S51→S57→S63→S69→S75→S81 T_5 → S6→S12→S18→S24→S30→S36→S42→S48→S54→S60→S66→S72→S78→S84
	28-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24‖S27 F27‖F30 S30‖S33 F33‖F36 S36‖S39 F39‖F42 S42‖S45 F45‖F48 S48‖S51 F51‖F54 S54‖S57 F57‖F60 S60‖S63 F63‖F66 S66‖S69 F69‖F72 S72‖S75 F75‖F78 S78‖S81 F81‖F84 S84	T_2 → S3→F6→S9→F12→S15→F18→S21→F24→S27→F30→S33→F36→S39→F42→ S45→F48→S51→F54→S57→F60→S63→F66→S69→F72→S75→F78→S81→F84 T_5 → F3→S6→F9→S12→F15→S18→F21→S24→F27→S30→F33→S36→F39→S42→ F45→S48→F51→S54→F57→S60→F63→S66→F69→S72→F75→S78→F81→S84
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F62 S62→S65 F65→F68 S68→S71 F71→F74 S74→S77 F77→F80 S80→S83 F83→F2 S2	T_3 → S5 T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44‖S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F62 S62→S65 F65→F68 S68→S71 F71→F74 S74→S77 F77→F80 S80→S83 F83→F2 S2	T_3 → S5→S47 T_6 → S44→S2
	4-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23‖F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44‖S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F62 S62→S65 F65‖F68 S68→S71 F71→F74 S74→S77 F77→F80 S80→S83 F83→F2 S2	T_3 → S5→F26→S47→F68 T_6 → F23→S44→F65→S2
	7-parallel	S5 F5→F8 S8→S11 F11→F14 S14‖S17 F17→F20 S20→S23 F23→F26 S26‖S29 F29→F32 S32→S35 F35→F38 S38‖S41 F41→F44 S44→S47 F47→F50 S50‖S53 F53→F56 S56→S59 F59→F62 S62‖S65 F65→F68 S68→S71 F71→F74 S74‖S77 F77→F80 S80→S83 F83→F2 S2	T_3 → S5→S17→S29→S41→S53→S65→S77 T_6 → S14→S26→S38→S50→S62→S74→S2
	14-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F26 S26‖S29 F29→F32 S32‖S35 F35→F38 S38‖S41 F41→F44 S44‖S47 F47→F50 S50‖S53 F53→F56 S56‖S59 F59→F62 S62‖S65 F65→F68 S68‖S71 F71→F74 S74‖S77 F77→F80 S80‖S83 F83→F2 S2	T_3 → S5→S11→S17→S23→S29→S35→S41→S47→S53→S59→S65→S71→S77→S83 T_6 → S8→S14→S20→S26→S32→S38→S44→S50→S56→S62→S68→S74→S80→S2
	28-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F26 S26‖S29 F29‖F32 S32‖S35 F35‖F38 S38‖S41 F41‖F44 S44‖S47 F47‖F50 S50‖S53 F53‖F56 S56‖S59 F59‖F62 S62‖S65 F65‖F68 S68‖S71 F71‖F74 S74‖S77 F77‖F80 S80‖S83 F83‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F26→S29→F32→S35→F38→S41→F44→ S47→F50→S53→F56→S59→F62→S65→F68→S71→F74→S77→F80→S83→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S26→F29→S32→F35→S38→F41→S44→ F47→S50→F53→S56→F59→S62→F65→S68→F71→S74→F77→S80→F83→S2

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Δ Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.

F = finish of a group.

T-T = Top-to-top or bottom-to-bottom or short-jumper connection.

→ = connected to start or finish of a group.

‖ = spot for change with respect to series connection.

TABLE 3-24

30-POLE 3-PHASE T-T CONNECTION TABLE

Phase		Connections	Leads
A	Series	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58→S61 F61→F64 S64→S67 F67→F70 S70→S73 F73→F76 S76→S79 F79→F82 S82→S85 F85→F88 S88	T_1 → S1 T_4 → S88
	2-parallels	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34→S37 F37→F40 S40→S43 F43‖F46 S46→S49 F49→F52 S52→S55 F55→F58 S58→S61 F61→F64 S64→S67 F67→F70 S70→S73 F73→F76 S76→S79 F79→F82 S82→S85 F85→F88 S88	T_1 → S1→F46 T_4 → F43→S88
	3-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16→S19 F19→F22 S22→S25 F25→F28 S28‖S31 F31→F34 S34→S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52→S55 F55→F58 S58‖S61 F61→F64 S64→S67 F67→F70 S70→S73 F73→F76 S76→S79 F79→F82 S82→S85 F85→F88 S88	T_1 → S1→S31→S61 T_4 → S28→S58→S88
	5-parallels	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13→F16 S16‖S19 F19→F22 S22→S25 F25→F28 S28→S31 F31→F34 S34‖S37 F37→F40 S40→S43 F43→F46 S46→S49 F49→F52 S52‖S55 F55→F58 S58→S61 F61→F64 S64→S67 F67→F70 S70‖S73 F73→F76 S76→S79 F79→F82 S82→S85 F85→F88 S88	T_1 → S1→S19→S37→S55→S73 T_4 → S16→S34→S52→S70→S88
	6-parallel	S1 F1→F4 S4→S7 F7→F10 S10→S13 F13‖F16 S16→S19 F19→F22 S22→S25 F25→F28 S28‖S31 F31→F34 S34→S37 F37→F40 S40→S43 F43‖F46 S46→S49 F49→F52 S52→S55 F55→F58 S58‖S61 F61→F64 S64→S67 F67→F70 S70→S73 F73‖F76 S76→S79 F79→F82 S82→S85 F85→F88 S88	T_1 → S1→F16→S31→F46→S61→F76 T_4 → F13→S28→F43→S58→F73→S88
	10-parallel	S1 F1→F4 S4→S7 F7‖F10 S10→S13 F13→F16 S16‖S19 F19→F22 S22→S25 F25‖F28 S28→S31 F31→F34 S34‖S37 F37→F40 S40→S43 F43‖F46 S46→S49 F49→F52 S52‖S55 F55→F58 S58→S61 F61‖F64 S64→S67 F67→F70 S70‖S73 F73→F76 S76→S79 F79‖F82 S82→S85 F85→F88 S88	T_1 → S1→F10→S19→F28→S37→F46→S55→F64→S73→F82 T_4 → F7→S16→F25→S34→F43→S52→F61→S70→F79→S88
	15-parallel	S1 F1→F4 S4‖S7 F7→F10 S10‖S13 F13→F16 S16‖S19 F19→F22 S22‖S25 F25→F28 S28‖S31 F31→F34 S34‖S37 F37→F40 S40‖S43 F43→F46 S46‖S49 F49→F52 S52‖S55 F55→F58 S58‖S61 F61→F64 S64‖S67 F67→F70 S70‖S73 F73→F76 S76‖S79 F79→F82 S82‖S85 F85→F88 S88	T_1 → S1→S7→S13→S19→S25→S31→S37→S43→S49→S55→S61→S67→S73→S79→S85 T_4 → S4→S10→S16→S22→S28→S34→S40→S46→S52→S58→S64→S70→S76→S82→S88
	30-parallel	S1 F1‖F4 S4‖S7 F7‖F10 S10‖S13 F13‖F16 S16‖S19 F19‖F22 S22‖S25 F25‖F28 S28‖S31 F31‖F34 S34‖S37 F37‖F40 S40‖S43 F43‖F46 S46‖S49 F49‖F52 S52‖S55 F55‖F58 S58‖S61 F61‖F64 S64‖S67 F67‖F70 S70‖S73 F73‖F76 S76‖S79 F79‖F82 S82‖S85 F85‖F88 S88	T_1 → S1→F4→S7→F10→S13→F16→S19→F22→S25→F28→S31→F34→S37→F40→S43→F46→S49→F52→S55→F58→S61→F64→S67→F70→S73→F76→S79→F82→S85→F88 T_4 → F1→S4→F7→S10→F13→S16→F19→S22→F25→S28→F31→S34→F37→S40→F43→S46→F49→S52→F55→S58→F61→S64→F67→S70→F73→S76→F79→S82→F85→S88
B	Series	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60→S63 F63→F66 S66→S69 F69→F72 S72→S75 F75→F78 S78→S81 F81→F84 S84→S87 F87→F90 S90	T_2 → S3 T_5 → S90
	2-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36→S39 F39→F42 S42→S45 F45‖F48 S48→S51 F51→F54 S54→S57 F57→F60 S60→S63 F63→F66 S66→S69 F69→F72 S72→S75 F75→F78 S78→S81 F81→F84 S84→S87 F87→F90 S90	T_2 → S3→F48 T_5 → F45→S90
	3-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18→S21 F21→F24 S24→S27 F27→F30 S30‖S33 F33→F36 S36→S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54→S57 F57→F60 S60‖S63 F63→F66 S66→S69 F69→F72 S72→S75 F75→F78 S78→S81 F81→F84 S84→S87 F87→F90 S90	T_2 → S3→S33→S63 T_5 → S30→S60→S90
	5-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15→F18 S18‖S21 F21→F24 S24→S27 F27→F30 S30→S33 F33→F36 S36‖S39 F39→F42 S42→S45 F45→F48 S48→S51 F51→F54 S54‖S57 F57→F60 S60→S63 F63→F66 S66→S69 F69→F72 S72‖S75 F75→F78 S78→S81 F81→F84 S84→S87 F87→F90 S90	T_2 → S3→S21→S39→S57→S75 T_5 → S18→S36→S54→S72→S90
	6-parallel	S3 F3→F6 S6→S9 F9→F12 S12→S15 F15‖F18 S18→S21 F21→F24 S24→S27 F27→F30 S30‖S33 F33→F36 S36→S39 F39→F42 S43→S45 F45‖F48 S48→S51 F51→F54 S54→S57 F57→F60 S60‖S63 F63→F66 S66→S69 F69→F72 S72→S75 F75‖F78 S78→S81 F81→F84 S84→S87 F87→F90 S90	T_2 → S3→F18→S33→F48→S63→F78 T_5 → F15→S30→F45→S60→F75→S90
	10-parallel	S3 F3→F6 S6→S9 F9‖F12 S12→S15 F15→F18 S18‖S21 F21→F24 S24→S27 F27‖F30 S30→S33 F33→F36 S36‖S39 F39→F42 S42→S45 F45‖F48 S48→S51 F51→F54 S54‖S57 F57→F60 S60→S63 F63‖F66 S66→S69 F69→F72 S72‖S75 F75→F78 S78→S81 F81‖F84 S84→S87 F87→F90 S90	T_2 → S3→F12→S21→F30→S39→F48→S57→F66→S75→F84 T_5 → F9→S18→F27→S36→F45→S54→F63→S72→F81→S90
	15-parallel	S3 F3→F6 S6‖S9 F9→F12 S12‖S15 F15→F18 S18‖S21 F21→F24 S24‖S27 F27→F30 S30‖S33 F33→F36 S36‖S39 F39→F42 S42‖S45 F45→F48 S48‖S51 F51→F54 S54‖S57 F57→F60 S60‖S63 F63→F66 S66‖S69 F69→F72 S72‖S75 F75→F78 S78‖S81 F81→F84 S84‖S87 F87→F90 S90	T_2 → S3→S9→S15→S21→S27→S33→S39→S45→S51→S57→S63→S69→S75→S81→S87 T_5 → S6→S12→S18→S24→S30→S36→S42→S48→S54→S60→S66→S72→S78→S84→S90
	30-parallel	S3 F3‖F6 S6‖S9 F9‖F12 S12‖S15 F15‖F18 S18‖S21 F21‖F24 S24‖S27 F27‖F30 S30‖S33 F33‖F36 S36‖S39 F39‖F42 S42‖S45 F45‖F48 S48‖S51 F51‖F54 S54‖S57 F57‖F60 S60‖S63 F63‖F66 S66‖S69 F69‖F72 S72‖S75 F75‖F78 S78‖S81 F81‖F84 S84‖S87 F87‖F90 S90	T_2 → S3→F6→S9→F12→S15→F18→S21→F24→S27→F30→S33→F36→S39→F42→S45→F48→S51→F54→S57→F60→S63→F66→S69→F72→S75→F78→S81→F84→S87→F90 T_5 → F3→S6→F9→S12→F15→S18→F21→S24→F27→S30→F33→S36→F39→S42→F45→S48→F51→S54→F57→S60→F63→S66→F69→S72→F75→S78→F81→S84→F87→S90
C	Series	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F62 S62→S65 F65→F68 S68→S71 F71→F74 S74→S77 F77→F80 S80→S83 F83→F86 S86→S89 F89→F2 S2	T_3 → S5 T_6 → S2
	2-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38→S41 F41→F44 S44→S47 F47‖F50 S50→S53 F53→F56 S56→S59 F59→F62 S62→S65 F65→F68 S68→S71 F71→F74 S74→S77 F77→F80 S80→S83 F83→F86 S86→S89 F89→F2 S2	T_3 → S5→F50 T_6 → F47→S2
	3-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20→S23 F23→F26 S26→S29 F29→F32 S32‖S35 F35→F38 S38→S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56→S59 F59→F62 S62‖S65 F65→F68 S68→S71 F71→F74 S74→S77 F77→F80 S80→S83 F83→F86 S86→S89 F89→F2 S2	T_3 → S5→S35→S65 T_6 → S32→S62→S2
	5-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17→F20 S20‖S23 F23→F26 S26→S29 F29→F32 S32→S35 F35→F38 S38‖S41 F41→F44 S44→S47 F47→F50 S50→S53 F53→F56 S56‖S59 F59→F62 S62→S65 F65→F68 S68→S71 F71→F74 S74‖S77 F77→F80 S80→S83 F83→F86 S86→S89 F89→F2 S2	T_3 → S5→S23→S41→S59→S77 T_6 → S20→S38→S56→S74→S2
	6-parallel	S5 F5→F8 S8→S11 F11→F14 S14→S17 F17‖F20 S20→S23 F23→F26 S26→S29 F29→F32 S32‖S35 F35→F38 S38→S41 F41→F44 S44→S47 F47‖F50 S50→S53 F53→F56 S56→S59 F59→F62 S62‖S65 F65→F68 S68→S71 F71→F74 S74→S77 F77‖F80 S80→S83 F83→F86 S86→S89 F89→F2 S2	T_3 → S5→F20→S35→F50→S65→F80 T_6 → F17→S32→F47→S62→F77→S2
	10-parallel	S5 F5→F8 S8→S11 F11‖F14 S14→S17 F17→F20 S20‖S23 F23→F26 S26→S29 F29‖F32 S32→S35 F35→F38 S38‖S41 F41→F44 S44→S47 F47‖F50 S50→S53 F53→F56 S56‖S59 F59→F62 S62→S65 F65‖F68 S68→S71 F71→F74 S74‖S77 F77→F80 S80→S83 F83‖F86 S86→S89 F89→F2 S2	T_3 → S5→F14→S23→F32→S41→F50→S59→F68→S77→F86 T_6 → F11→S20→F29→S38→F47→S56→F65→S74→F83→S2
	15-parallel	S5 F5→F8 S8‖S11 F11→F14 S14‖S17 F17→F20 S20‖S23 F23→F26 S26‖S29 F29→F32 S32‖S35 F35→F38 S38‖S41 F41→F44 S44‖S47 F47→F50 S50‖S53 F53→F56 S56‖S59 F59→F62 S62‖S65 F65→F68 S68‖S71 F71→F74 S74‖S77 F77→F80 S80‖S83 F83→F86 S86‖S89 F89→F2 S2	T_3 → S5→S11→S17→S23→S29→S35→S41→S47→S53→S59→S65→S71→S77→S83→S89 T_3 → S8→S14→S20→S26→S32→S38→S44→S50→S56→S62→S68→S74→S80→S86→S2
	30-parallel	S5 F5‖F8 S8‖S11 F11‖F14 S14‖S17 F17‖F20 S20‖S23 F23‖F26 S26‖S29 F29‖F32 S32‖S35 F35‖F38 S38‖S41 F41‖F44 S44‖S47 F47‖F50 S50‖S53 F53‖F56 S56‖S59 F59‖F62 S62‖S65 F65‖F68 S68‖S71 F71‖F74 S74‖S77 F77‖F80 S80‖S83 F83‖F86 S86‖S89 F89‖F2 S2	T_3 → S5→F8→S11→F14→S17→F20→S23→F26→S29→F32→S35→F38→S41→F44→S47→F50→S53→F56→S59→F62→S65→F68→S71→F74→S77→F80→S83→F86→S89→F2 T_6 → F5→S8→F11→S14→F17→S20→F23→S26→F29→S32→F35→S38→F41→S44→F47→S50→F53→S56→F59→S62→F65→S68→F71→S74→F77→S80→F83→S86→F89→S2

Y Connection: Connect T_1, T_2, T_3, to line leads; connect T_4, T_5, T_6, together.

Δ Connection: T_1, T_6 together to line lead; T_2, T_4 together to line lead; T_3, T_5 together to line lead.

S = start of a group.
F = finish of a group.

→ = connected to start or finish of a group.
‖ = spot for change with respect to series connection.
T-T = Top-to-top or bottom-to-bottom or short-jumper connection.

CHAPTER 4

BALANCED FRACTIONAL-SLOT LAP WINDINGS (BALANCED LAP WINDINGS WITH UNEQUAL COIL GROUPING)

4-1. Average Number of Slots Per Pole Per Phase. The lap windings described in Chapter 3 have an equal number of single coils in all pole-phase groups. These are the windings in which the number of slots per pole per phase is an integer. A 3-phase, 8-pole stator with 72 slots has $\frac{72}{3 \times 8} = 3$ slots per pole per phase, and each pole-phase group consists of 3 single coils. All pole-phase groups are equal. A 3-phase, 8-pole stator with 66 slots instead of 72 will have $\frac{66}{3 \times 8} = \frac{11}{4} = 2\ 3/4$ slots per pole per phase. Since the number of single coils in a pole-phase group can be only a whole number, i.e., a pole-phase group can comprise only an integral number of slots, the figure 2 3/4 can be realized only as an average value. If each phase would have, in each 4 of the 8 poles, 3 coil groups with 3 single coils and 1 coil group with 2 single coils, the average number of coils per group would be $\frac{3 + 3 + 3 + 2}{4} = \frac{11}{4} = 2\ 3/4$. Thus, a winding with a fractional number of slots per pole per phase can be realized by making the pole-phase groups have unequal numbers of single coils. Such windings are called Windings with Unequal Coil Grouping or Fractional-slot Windings, because the average number of slots per pole per phase of these windings is a fractional number.

The Master Tables 3-4 and 3-5 give the average number of slots per pole per phase for different numbers of slots and different numbers of poles. Table 3-4 refers to 2-phase windings and Table 3-5 to 3-phase windings. For example, a 2-phase, 6-pole winding with 44 slots has an average of 3 2/3 slots per pole per phase, and a 3-phase, 8-pole winding with 66 slots has an average of 2 3/4 slots per pole per phase. The values of slots per pole per phase, i.e., spp, for balanced fractional-slot windings are shown in normal print in the tables. The values of spp for unbalanced fractional-slot windings are shown in italics marked by an asterisk (See Arts. 4-3 and 4-6).

4-2. Connection Diagrams and Coil Grouping. The Connection Diagrams of the fractional-slot windings are the same as those of the integral-slot windings; hence the Connection Diagram of a 3-phase, 8-pole winding with 2 3/4 slots per pole per phase connected one circuit star is given by Fig. 3-65 just as is the 3-phase, 8-pole integral-slot winding. However, as explained in Art. 4-1, the lines which represent the individual pole-phase groups represent, in the fractional-slot windings, groups having different numbers of single coils. In the example of the 3-phase, 8-pole winding with 66 slots, these lines represent the pole-phase groups with 3 single coils as well as those with 2 single coils.

In order to connect a fractional-slot winding, it is not enough to have the Connection Diagram, but it is also necessary to know the sequence of the larger and smaller pole-phase groups around the stator or rotor, i.e., the coil grouping.

The 3-phase, 8-pole stator winding considered above has 8 x 3 = 24 (= No. of poles x No. of phases) pole-phase groups of which 18 have 3 single coils and 6 have 2 single coils. Their distribution around the stator should be:

3 3 3 2   3 3 3 2   3 3 3 2   3 3 3 2   3 3 3 2   3 3 3 2

Assigning the first group to phase A, the second group has to be assigned to phase C, the third to phase B, the fourth group again to phase A and so on, corresponding to the Connection Diagram (Fig. 3-65). In doing this, it will be found that the number of single coils (or slots) and also the number of groups with 3 single coils and the number of groups with 2 single coils are the same for all 3 phases. Note that the coil grouping consists of equal distribution parts (6 in this case) which repeat themselves. Each part consists of the groups:

3 3 3 2

If the grouping of one part and the number of repetitions are given (as in Table 4-2), the coil grouping for the whole winding is then fixed. This and the Connection Diagram suffice to accomplish the winding.

4-3. Coil Grouping Tables and How to Use Them.

Tables 4-1 and 4-2 of this chapter, and Tables 5-1 and 5-2, of Chapter 5 give the coil grouping of one distribution part, the number of repetitions of this grouping, and the number of parallel paths. The fractional-slot windings considered in this chapter are the

Balanced Fractional-slot Windings; those considered in Chapter 5 are the Unbalanced Fractional-slot Windings (see Art. 4-6).

The use of Tables 4-1 and 4-2 will be explained by some examples. Consider a 2-phase, 10-pole winding with 68 slots. Master Table 3-4 shows the average number of slots per pole per phase, i.e., spp = 3 2/5. The whole number, or integral part, of this spp is 3, and the fractional part is 2/5. For the fraction 2/5, Table 4-1 yields the following grouping for one distribution part:

1 0 1 0 0

Since the integer of this spp is 3, this figure has to be added to all numbers of the grouping obtained from the Table, i.e., the coil grouping of one distribution part is:

4 3 4 3 3

Furthermore, Table 4-1 states that the grouping repeats $2 \times \frac{\text{No. of poles}}{5} = 2 \times \frac{10}{5} = 4$ times. Therefore, the grouping of the total winding is:

4 3 4 3 3   4 3 4 3 3   4 3 4 3 3   4 3 4 3 3
A B A B A   B A B A B   A B A B A   B A B A B

The letters A and B indicate the phases to which the pole-phase groups are assigned.

Table 4-1 shows also the maximum possible number of parallel paths. For the winding of the example, it is $\frac{\text{No. of poles}}{5} = 10/5 = 2$, while the 10-pole, integral-slot lap winding has a maximum of 10 parallel paths.

Consider further a 3-phase, 14-pole winding with 96 slots. Master Table 3-5 shows that the average number of slots per pole per phase is 2 2/7. Table 4-2 yields for the fraction 2/7 the following grouping for one distribution part:

1 0 0 1 0 0 0

Since the integer of this spp is 2, this figure is to be added to all numbers of the grouping obtained from the Table, i.e., the coil grouping of one distribution part is:

3 2 2 3 2 2 2

Moreover, Table 4-2 states that the grouping repeats $3 \times \frac{\text{No. of poles}}{7} = 3 \times \frac{14}{7} = 6$ times. Therefore, the grouping of the total winding is:

3 2 2 3 2 2 2   3 2 2 3 2 2 2   3 2 2 3 2 2 2
A C B A C B A   C B A C B A C   B A C B A C B

3 2 2 3 2 2 2   3 2 2 3 2 2 2   3 2 2 3 2 2 2
A C B A C B A   C B A C B A C   B A C B A C B

The letters A, C, B, indicate the phases to which the pole-phase groups are assigned. The various connection diagrams for this winding are Figs. 3-111, 3-112, 3-115, 3-117, 3-118, and 3-121. From Table 4-2, it follows that the maximum possible number of parallel paths is $\frac{14}{7} = 2$.

The beginnings of the phases are as given in the Connection Diagrams mentioned above. They are not exactly 2/3 of a pole pitch apart, as is the case in the integral-slot lap winding. Despite this, the winding is balanced.

As pointed out, the coil-grouping Tables 4-1 and 4-2, together with Tables 3-4 and 3-5, and the Connection Diagrams are all that is required for the layout of balanced fractional-slot lap windings. The maximum number of parallel paths shown in Tables 4-1 and 4-2 is independent of the kind of jumper (short or long, see Arts. 3-5 and 3-10) used in 2-phase windings and in those 3-phase windings in which the denominator of the fraction of spp is odd. In 3-phase windings with an even denominator of the fraction, the maximum number of parallel paths as given in Table 4-2 is to be divided by 2, when the long jumper is used. For example, Table 4-2 shows that a 4-pole winding with the fraction of spp $= \frac{1}{2}$ can have a maximum of $\frac{4}{2} = 2$ parallel paths. When the long jumper is used, this winding can be connected in only $\frac{2}{2} = 1$ circuit, i.e. connected in series. An 8-pole winding with the fraction of spp $= \frac{1}{2}$ can have (according to Table 4-2) maximum of $\frac{8}{2} = 4$ parallel paths, but is limited to $\frac{4}{2} = 2$ parallel paths when the long jumper is used. The winder should ascertain that each path of each phase has the same number of single coils, before using the long jumper for 3-phase windings with parallel circuits and an even denominator of the fraction of spp. As mentioned in Art. 3-3, the short-jumper connection is the most commonly used and is to be assumed unless otherwise specified. Note that, carefulness is necessary when applying Tables, since misprints are not always unavoidable. The following articles give additional information which permits checking the Tables available or finding the coil grouping without using Tables.

4-4. Number of Larger and Smaller Pole-phase Groups; Number of Equal Winding Parts. A thorough inspection of the fractional number which represents the average number of slots per pole per phase yields a great deal of information about the coil grouping. Consider again the example of Art. 4-1 in which the number of slots per pole per phase is 2 3/4. This figure lies between the integers 2 and 3 and, therefore, some pole-phase groups will have 3 single coils and some 2 single coils. Other coil groups will not appear. Since the figure 2 3/4 is closer to 3 than to 2, there will be more groups with 3 single coils than with 2 single coils, and it is apparent that in each 4 consecutive poles there will be, per phase, 3 pole-phase groups with 3 single coils and 1 pole-phase group with 2 single coils; 3 is the numerator of the fraction 3/4, and 1 is the difference between the denominator 4 of the fraction and its numerator (4 - 3 = 1). Thus, the numerator of the fraction represents, per phase, the number of the larger pole-phase groups, and the difference between denominator and numerator of the fraction represents the number of the smaller pole-phase groups. The denominator of the fraction represents also the number of poles in which the unequal distribution of pole-phase groups is accomplished, and the average value of spp is achieved. The number of equal parts in the whole winding will be equal to the number of times the denominator of the fraction is contained in the number of poles; in the example considered, there are 8/4 or 2 equal winding parts.

Note that the number of repeatable distribution parts is different from the number of repeatable winding parts. There are twice as many distribution parts as there are winding parts in the 2-phase windings, and 3 times as many in the 3-phase windings. Thus it suffices to know the coil grouping of half of a repeatable winding part for a 2-phase winding and of a third of a repeatable winding part for a 3-phase winding, in order to know the coil grouping of the whole winding.

The foregoing considerations will be demonstrated once more by an example of a 3-phase, 16-pole winding in 174 slots. The average number of slots per pole per phase is

$$\frac{174}{3 \times 16} = \frac{58}{16} = \frac{29}{8} = 3\ 5/8.$$

Note that the number of slots per pole per phase must be expressed by the smallest possible fraction. Hence it would be incorrect to write here spp = $\frac{58}{16}$ or 3 10/16; it should be spp = 3 5/8. This figure then indicates that there will be, in each phase, a larger number of pole-phase groups consisting of 4 single coils than there are pole-phase groups consisting of 3 single coils, and, further, that in 8 (= denominator of the fraction) consecutive poles there will be, per phase, 5 (= numerator of the fraction) pole-phase groups with the larger number of coils and 8 - 5 = 3 (= denominator - numerator) pole-phase groups with the smaller number of coils. Eight poles make a repeatable winding part. Since the number of poles is 16, there are 2 repeatable winding parts in the winding. There are 3 x 2 = 6 repeatable distribution parts.

4-5. General Rules. If, in general terms, spp = I $\frac{n}{d}$, where I is the integral part of the fractional number, and n and d are the numerator and denominator of the fraction, d poles then constitute a repeatable part in which there will be, per phase, n pole-phase groups with I plus 1 single coils and d minus n pole-phase groups with I single coils. The number of repeatable winding parts is equal to the number of poles divided by d.

4-6. Conditions of Balance. It has been mentioned that in this chapter only the balanced fractional-slot windings will be considered. These are the windings for which

$$\frac{\text{No. of poles}}{d} = \text{an integer} \qquad (1)$$

$$\frac{d}{\text{No. of phases}} = \text{fractional number} \qquad (2)$$

When these 2 conditions are satisfied, the winding is balanced, i.e., the voltages generated in the phases have the same magnitude and are displaced from each other by the same angle. Some examples will be considered.

(1) The 3-phase, 8-pole winding of Art. 4-1 with spp = 2 3/4 is a balanced winding because the number of poles 8 divided by the denominator d = 4 is an integer (= 2), and the denominator d = 4 divided by the number of phases 3 is a fractional number (1 1/3).

(2) The 3-phase, 16-pole winding of Art. 4-4 with spp = 3 5/8 is a balanced winding because the number of poles 16 divided by

the denominator d = 8 is an integer, and the denominator d = 8 divided by the number of phases 3 is a fractional number.

(3) Consider a 3-phase, 6-pole winding with 60 slots. The average number of slots per pole per phase is

$$\frac{60}{3 \times 6} = \frac{20}{6} = \frac{10}{3} = 3\ 1/3$$

This winding is unbalanced because the denominator d = 3 divided by the number of phases 3 is an integer, i.e., because the second condition of balance is not satisfied. Note that the number of slots per phase $\frac{60}{3} = 20$ is an integer. Equal numbers of slots for all phases is not a proof of balance.

(4) Consider a 2-phase, 12-pole winding with 80 slots. The average number of slots per pole per phase is

$$\frac{80}{2 \times 12} = \frac{40}{12} = \frac{10}{3} = 3\ 1/3$$

This winding is balanced because the number of poles 12 divided by the denominator d = 3 is an integer,and the denominator d = 3 divided by the number of phases 2 is a fractional number. Apparently, all 2-phase windings in which the denominator of the fraction is divisible by 2 and all 3-phase windings in which the denominator of the fraction is divisible by 3 are unbalanced.

Unbalanced windings are usually avoided because they may produce vibrations, noise, and additional losses in the copper. As mentioned previously, the unbalanced lap windings are treated in Chapter 5.

4-7. Number of Parallel Circuits. It has been pointed out in Art. 4-5 that the denominator of the fraction d represents the number of poles of a repeatable winding part. In the example of the 3-phase, 8-pole winding with 2 3/4 slots per pole per phase, 4 poles make a repeatable part of the winding, i.e., 4 poles are necessary to make the winding have an average spp = 2 3/4. Since there are 8 poles, the number of repeatable winding parts is equal to 8/4 = 2. From this, it follows that only 2 parallel circuits are possible, contrary to the 8-pole lap winding with spp an integer which may have 8 parallel circuits. In the example of the 3-phase, 16-pole winding with spp = 3 5/8, again only 2 parallel circuits are possible. In general, the maximum possible number of parallel circuits is equal to the number of poles divided by the denominator of the fraction d, i.e., it is equal to the number of repeatable winding parts.

The number of parallel circuits may be made less than the number of repeatable winding parts but then the latter number must be divisible by the number of parallel circuits. Consider a 3-phase, 48-pole winding in 324 slots. The average value of spp is

$$\frac{324}{3 \times 48} = \frac{108}{48} = \frac{9}{4} = 2\ 1/4$$

d = 4 poles make a repeatable winding part, and the number of repeatable parts is equal to $\frac{48}{4} = 12$. This is also the maximum possible number of parallel paths. However, each phase can have also 2, or 3, or 4, or 6 parallel paths because the maximum possible number of parallel paths (12) is divisible by each of these 4 numbers.

Consider a 3-phase, 28-pole winding in 210 slots. The average spp = $\frac{210}{3 \times 28} = \frac{5}{2}$. d = 2 poles makes a repeatable winding part, and the number of repeatable winding parts is equal to $\frac{28}{2} = 14$. This is also the maximum possible number of parallel paths. However, each phase can have also 2 or 7 parallel paths but not 4. The maximum possible number of parallel paths, 14, is divisible by 2 and 7, but not by 4.

4-8, Layout of a Balanced 2-Phase Winding. The laying out of a fractional-slot winding involves the determination of the sequence in which the larger and smaller pole-phase groups have to be arranged. It is not enough that the conditions of balance (Art. 4-6) are satisfied; it is also necessary that the unequal coil groups be distributed around the stator or rotor in a certain sequence in order that the winding is balanced.

There are many ways to distribute the coils and get a balanced winding (see Appendix 2). The method of distributing shown in this chapter yields the coil grouping most often used. It will be explained by an example of a 2-phase, 10-pole stator with 68 slots. The number of slots per pole per phase is then

$$\frac{68}{2 \times 10} = \frac{34}{10} = \frac{17}{5} = 3\ 2/5$$

Five poles make a repeatable part of the winding. There are $\frac{10}{5} = 2$ repeatable winding parts. In each part there are, per phase, 2 (= n) pole-phase groups with 4 = (I + 1) = (3 + 1) single coils and 3 (= d minus n) = (5 - 2) pole-phase groups with 3 (= I) single coils. In order to find the group distribution around the stator,

(a) Write the series 1 x spp; 2 x spp; 3 x spp; . . . up to d x spp.

(b) Disregard the fractions, and add 1 to all integers of this series except the last one.

(c) Write 0 (zero) to the left of the second series (b) and determine the differences between adjacent numbers.

The last series shows then the sequence of the pole-phase groups for half of the repeatable winding part. For the other half of the repeatable winding part, the coil distribution is the same as for the first part. For the example considered, these rules yield the following:

(a) 3 2/5 6 4/5 10 1/5 13 3/5 17
(b) 0 4 7 11 14 17
(c) 4 3 4 3 3

which is the coil grouping for one half of the repeatable winding part. This grouping repeated twice gives the pole-phase group distribution for the whole repeatable winding part. It is

4 3 4 3 3 4 3 4 3 3 (L)

These numbers repeated as many times as there are repeatable winding parts, i.e., in the example considered, twice, yield the coil grouping around the whole stator.

The last series (L) shows that a repeatable winding part has 4 pole-phase groups with 4 single coils and 6 pole-phase groups with 3 single coils. It has been determined previously, from the fractional number 3 2/5, that each phase should have 2 pole-phase groups with 4 single coils and 3 pole-phase groups with 3 single coils; for both phases, this gives 4 pole-phase groups with 4 single coils and 6 pole-phase groups with 3 single coils in accordance with series (L).

If the first pole-phase group of the series (c) or (L) is assigned to phase A, the second group is to be assigned to phase B, the third group to phase A, and so on, as was explained in Art. 3-4 (see for example Fig. 3-1a).

Summarizing, the rules given under (a), (b), and (c) yield, in 2-phase windings, the pole-phase distribution for half of a repeatable part of the winding. Repeated twice, the group distribution for one repeatable part of the winding is obtained. The latter distribution repeated as many times as there are repeatable winding parts gives the coil grouping of the whole winding. The phase assignment of the groups is A and B in succession.

Another example of a 2-phase, 28-pole stator with 136 slots will be considered. For this winding,

$$\text{spp} = \frac{136}{2 \times 8} = \frac{68}{28} = \frac{17}{7} = 2\ 3/7$$

Thus,

(a) 2 3/7 4 6/7 7 2/7 9 5/7 12 1/7 14 4/7 17
(b) 0 3 5 8 10 13 15 17
(c) 3 2 3 2 3 2 2

The last series repeated gives the coil grouping for one repeatable winding part. Since there are $\frac{28}{7} = 4 = \left(\frac{\text{No. of poles}}{d}\right)$ repeatable winding parts, the series obtained from (c) must be repeated 2 x 4 = 8 times, in order to obtain the coil grouping for the whole winding. The distribution between the 2 phases under the different poles for 1 repeatable winding part is:

Phase.	A B	A B	A B	A B	A B	A B	A B
Coils per group. .	3 2	3 2	3 2	2 3	2 3	2 3	2 2
Pole No.	1	2	3	4	5	6	7

It should be remembered that in a 2-phase winding there are 2 coil groups per pole, one for each phase (see Fig. 3-1a).

4-9. Beginnings of Phases in 2-Phase Windings. As in the integral-slot windings, the beginnings of the phases lie one pole-phase group apart, i.e., the starts of 2 consecutive pole-phase groups can be used as phase beginnings. In the integral-slot windings, this corresponds to half a pole pitch; in the fractional-slot windings the distance between the phase beginnings is somewhat different from half a pole pitch. Consider Fig. 3-24 which may represent an integral-slot as well as a fractional-slot winding. The phase beginnings shown there are correct for both kinds of windings.

However, it is not necessary to take the starts of 2 consecutive pole-phase groups as phase beginnings. The starts of pole-phase groups 1 and 6 which lie 5 pole-phase groups apart also can be used as phase beginnings. In general, in 2-phase windings the beginnings of the phases must lie 1 plus zero or (an even integer x 2) pole-phase groups apart.

4-10. Layout of a Balanced 3-Phase Winding. The considerations are here the same as in the case of the 2-phase winding. The problem is to determine the sequence of the larger and smaller coil groups around the stator (or rotor). As for the 2-phase windings, the most often-used coil grouping will be considered. Other coil groupings which also yield balanced windings are discussed in Appendix 2.

The coil grouping in consideration will be explained by an example of a 3-phase, 20-pole stator with 216 slots. The number of slots per pole per phase is then

$$\frac{216}{3 \times 20} = \frac{72}{20} = \frac{18}{5} = 3\ 3/5$$

Five (= d) poles make a repeatable part of the winding. There are $\frac{20}{5} = 4$ $\left(= \frac{\text{No. of poles}}{d}\right)$ repeatable winding parts. In each part there are, per phase, 3 (= n) pole-phase groups with (I + 1) = (3 + 1) = 4 single coils and 2 = (d - n) = (5 - 3) pole-phase groups with 3 (= I) single coils. In order to find the group distribution around the stator, apply the same rules as for the 2-phase windings, i.e.,

(a) Write the series 1 x spp; 2 x spp; 3 x spp; . . . up to d x spp.

(b) Disregard the fractions and add 1 to all integers of this series except the last one.

(c) Write 0 (zero) to the left of the second series (b), and determine the differences between adjacent numbers.

The last series shows then the sequence of the coil groups for a third of a repeatable winding part. For each of the other 2 thirds, the coil grouping is the same as for the first third, i.e., in order to get the coil grouping for the whole repeatable winding part, the grouping obtained under (c) must be repeated 3 times. For the example considered, the rules (a), (b), and (c) yield:

(a)			3 3/5		7 1/2		10 4/5		14 2/5		18
(b)	0		4		8		11		15		18
(c)		4		4		3		4		3	

which is the pole-phase group distribution for a third of the repeatable winding part. This distribution, repeated 3 times, gives the coil group distribution for the whole repeatable winding part. It is

Coils per group. .	4 4 3	4 3 4	4 3 4	3 4 4	3 4 3	(L)'
Phase.	A C B	A C B	A C B	A C B	A C B	
Pole No.	1	2	3	4	5	

If the first pole-phase group is assigned to phase A, the second pole-phase group is to be assigned to phase C, the third group to phase B, the fourth group again to phase A, and so on, in accordance with the Connection Diagrams of Chapter 3 (see, for example, Fig. 3-3a).

In order to find the coil group distribution for the total winding, the coil grouping (L)' of the repeatable winding part is to be repeated as many times as there are repeatable parts, i.e., in the example considered, 4 times. In general, the grouping given by series (c) is to be repeated in 3-phase windings $3 \times \left(\frac{\text{No. of poles}}{d}\right)$ times.

Another example of a 3-phase, 14-pole winding with 108 slots will be considered. For this winding,

$$\text{spp} = \frac{108}{3 \times 14} = \frac{36}{14} = \frac{18}{7} = 2\ 4/7$$

Thus,

(a)		2 4/7	5 1/7	7 5/7	10 2/7	12 6/7	15 3/7	18
(b)	0	3	6	8	11	13	16	18
(c)	3	3	2	3	2	3	2	
Phase	A	C	B	A	C	B	A	

The coil grouping under (c) repeated $3 \times \frac{14}{7} = 6$ times gives the grouping of the total winding. The letters A, C, B show how the pole-phase groups are assigned to the different phases. The Connection Diagrams of this winding are given by Figs. 3-111, 3-112, 3-115, 3-117, 3-118, and 3-121.

4-11. Beginnings of Phases in 3-Phase Windings. As in the integral-slot lap windings, the beginnings of the phases lie 2 pole-phase groups apart, i.e., the starts of any 3 groups which are 2 pole-phase groups apart can be used as beginnings of the 3 phases. Consider the 8-pole winding (Fig. 3-65). The beginnings of the phases are the starts of the pole-phase groups 1, 3, and 5. In the integral-slot winding the distances between the starts of groups 1 and 3, and 3 and 5, are equal exactly to 2/3 of a pole pitch. This is not the case with fractional-slot windings, since the coil groups have different numbers of single coils. In Fig. 3-65, the starts of groups 1, 3, and 11, or the starts of groups 1, 9, and 17, also can be taken as beginnings of the phases, i.e., each of the beginnings 1, 3, and 5 can be replaced by one which belongs to the same phase and lies 6 pole-phase groups apart from it. So, by choosing the starts of groups 1, 3, and 11, instead of the starts of 1, 3, and 5, as beginnings, group 5 is replaced by group 11 which lies 6 pole-phase groups apart from 5.

In general, in 3-phase windings, the beginnings of the phases must lie 2 plus zero or (an even integer x 3) pole-phase groups apart.

4-12. Simplification in the Layout of Balanced 2-Phase and 3-Phase Windings. It follows from the previous considerations that it is the fraction of spp which determines the number of larger and smaller pole-phase groups. It is also only the fraction of the spp which determines the coil grouping of one distribution part of the winding (= 1/2 of the repeatable winding part in 2-phase windings and 1/3 of the repeatable winding part in 3-phase windings). As an example, the 3-phase, 14-pole winding of Art. 4-10 will be considered with 2 different numbers of slots, namely, with 108 slots as before and with 66 slots. For 108 slots, spp = 2 4/7; for 66 slots, spp = $\frac{66}{3 \times 14} = \frac{22}{14} = \frac{11}{7}$ = 1 4/7. Applying the method shown previously, the coil grouping of one repeatable distribution part is:

3 3 2 3 2 3 2	for spp = 2 4/7
2 2 1 2 1 2 1	for spp = 1 4/7

The grouping for spp = 1 4/7 can be obtained from that for spp = 2 4/7 by subtracting 1 from all numbers corresponding to the latter, and vice versa, the grouping for spp = 2 4/7 can be obtained from that for 1 4/7 by adding 1 to all numbers corresponding to spp = 1 4/7.

It can be seen from this example that the distribution of larger and smaller pole-phase groups is determined only by the fraction of spp. The integral part of spp determines only the absolute values of single coils in the groups but not the grouping. It follows from this that the grouping can be determined for the fraction alone and then the integral part of spp added to the numbers found for the fraction.

Again, the 3-phase, 14-pole winding with 108 slots of Art. 4-10 will be considered. Here, the spp = 2 4/7. The fraction is 4/7. Applying the method of layout shown previously, the sequence of larger and smaller coil groups for a third of a repeatable part of the winding is as follows:

(a) 4/7 1 1/7 1 5/7 2 2/7 2 6/7 3 3/7 4
(b) 0 1 2 2 3 3 4 4
(c) 1 1 0 1 0 1 0

The last series (c) shows the sequence of the larger and smaller pole-phase groups. Adding 2 to all numbers of the (c) series, i.e., adding the integral part of spp, the coil grouping with the correct numbers of single coils in the groups will be obtained. This is:

3 3 2 3 2 3 2

This result is in accordance with that found in Art. 4-10.

The Tables 4-1 and 4-2 are set up on the basis of the considerations of this article. They give only the sequence of the larger and smaller pole-phase groups. In order to determine the grouping with the real numbers of single coils in the groups, the integral part of spp is to be added to the numbers given in the Tables.

TABLE 4-1. COIL GROUPING FOR 2-PHASE WINDINGS

Fraction of spp	Coil Grouping (Sequence of the larger and smaller pole-phase groups)	The coil grouping repeats (2 times No. of poles) divided by	Maximum No. of parallel paths = No. of poles divided by
1/3	1 0 0	3	3
2/3	1 1 0		
1/5	1 0 0 0 0	5	5
2/5	1 0 1 0 0		
3/5	1 1 0 1 0		
4/5	1 1 1 1 0		
1/7	1 0 0 0 0 0 0	7	7
2/7	1 0 0 1 0 0 0		
3/7	1 0 1 0 1 0 0		
4/7	1 1 0 1 0 1 0		
5/7	1 1 1 0 1 1 0		
6/7	1 1 1 1 1 1 0		
1/9	1 0 0 0 0 0 0 0 0	9	9
2/9	1 0 0 0 1 0 0 0 0		
4/9	1 0 1 0 1 0 1 0 0		
5/9	1 1 0 1 0 1 0 1 0		
7/9	1 1 1 1 0 1 1 1 0		
8/9	1 1 1 1 1 1 1 1 0		
1/11	1 0 0 0 0 0 0 0 0 0 0	11	11
2/11	1 0 0 0 0 1 0 0 0 0 0		
3/11	1 0 0 1 0 0 0 1 0 0 0		
4/11	1 0 1 0 0 1 0 0 1 0 0		
5/11	1 0 1 0 1 0 1 0 1 0 0		
6/11	1 1 0 1 0 1 0 1 0 1 0		
7/11	1 1 0 1 1 0 1 1 0 1 0		
8/11	1 1 1 0 1 1 1 0 1 1 0		
9/11	1 1 1 1 1 0 1 1 1 1 0		
10/11	1 1 1 1 1 1 1 1 1 1 0		
1/13	1 0 0 0 0 0 0 0 0 0 0 0 0	13	13
2/13	1 0 0 0 0 0 1 0 0 0 0 0 0		
3/13	1 0 0 0 1 0 0 0 1 0 0 0 0		
4/13	1 0 0 1 0 0 1 0 0 1 0 0 0		
5/13	1 0 1 0 0 1 0 1 0 0 1 0 0		
6/13	1 0 1 0 1 0 1 0 1 0 1 0 0		
7/13	1 1 0 1 0 1 0 1 0 1 0 1 0		
8/13	1 1 0 1 1 0 1 0 1 1 0 1 0		
9/13	1 1 1 0 1 1 0 1 1 0 1 1 0		
10/13	1 1 1 1 0 1 1 1 0 1 1 1 0		
11/13	1 1 1 1 1 1 0 1 1 1 1 1 0		
12/13	1 1 1 1 1 1 1 1 1 1 1 1 0		

The coil grouping shown applies to the corresponding fraction of spp. In order to find the grouping for spp equal to the fraction plus an integer, add the integer to the values shown under the coil grouping.

TABLE 4-2. COIL GROUPING FOR 3-PHASE WINDINGS

Fraction of spp	Coil Grouping (Sequence of larger and smaller pole-phase groups)	The coil grouping shown repeats (3 times the No. of poles) divided by	Maximum No. of parallel paths = No. of poles divided by
1/2	1 0	2	2
1/4 3/4	1 0 0 0 1 1 1 0	4	4
1/5 2/5 3/5 4/5	1 0 0 0 0 1 0 1 0 0 1 1 0 1 0 1 1 1 1 0	5	5
1/7 2/7 3/7 4/7 5/7 6/7	1 0 0 0 0 0 0 1 0 0 1 0 0 0 1 0 1 0 1 0 0 1 1 0 1 0 1 0 1 1 1 0 1 1 0 1 1 1 1 1 1 0	7	7
1/8 3/8 5/8 7/8	1 0 0 0 0 0 0 0 1 0 1 0 0 1 0 0 1 1 0 1 1 0 1 0 1 1 1 1 1 1 1 0	8	8
1/10 3/10 7/10 9/10	1 0 0 0 0 0 0 0 0 0 1 0 0 1 0 0 1 0 0 0 1 1 1 0 1 1 0 1 1 0 1 1 1 1 1 1 1 1 1 0	10	10

TABLE 4-2 - Continued

Fraction of spp	Coil Grouping (Sequence of larger and smaller pole-phase groups)	The coil grouping shown repeats (3 times the No. of poles) divided by	Maximum No. of parallel paths = No. of poles divided by
1/11	1 0 0 0 0 0 0 0 0 0 0	11	11
2/11	1 0 0 0 0 1 0 0 0 0 0		
3/11	1 0 0 1 0 0 0 1 0 0 0		
4/11	1 0 1 0 0 1 0 0 1 0 0		
5/11	1 0 1 0 1 0 1 0 1 0 0		
6/11	1 1 0 1 0 1 0 1 0 1 0		
7/11	1 1 0 1 1 0 1 1 0 1 0		
8/11	1 1 1 0 1 1 1 0 1 1 0		
9/11	1 1 1 1 1 0 1 1 1 1 0		
10/11	1 1 1 1 1 1 1 1 1 1 0		
1/13	1 0 0 0 0 0 0 0 0 0 0 0 0	13	13
2/13	1 0 0 0 0 0 1 0 0 0 0 0 0		
3/13	1 0 0 0 1 0 0 0 1 0 0 0 0		
4/13	1 0 0 1 0 0 1 0 0 1 0 0 0		
5/13	1 0 1 0 0 1 0 1 0 0 1 0 0		
6/13	1 0 1 0 1 0 1 0 1 0 1 0 0		
7/13	1 1 0 1 0 1 0 1 0 1 0 1 0		
8/13	1 1 0 1 1 0 1 0 1 1 0 1 0		
9/13	1 1 1 0 1 1 0 1 1 0 1 1 0		
10/13	1 1 1 1 0 1 1 1 0 1 1 1 0		
11/13	1 1 1 1 1 1 0 1 1 1 1 1 0		
12/13	1 1 1 1 1 1 1 1 1 1 1 1 0		
1/14	1 0 0 0 0 0 0 0 0 0 0 0 0 0	14	14
3/14	1 0 0 0 1 0 0 0 0 1 0 0 0 0		
5/14	1 0 1 0 0 1 0 0 1 0 0 1 0 0		

TABLE 4-2 - Continued

Fraction of spp	Coil Grouping (Sequence of larger and smaller pole-phase groups)	The coil grouping shown repeats (3 times the No. of poles) divided by	Maximum No. of parallel paths = No. of poles divided by
9/14	1 1 0 1 1 0 1 1 0 1 1 0 1 0	14	14
11/14	1 1 1 1 0 1 1 1 1 0 1 1 1 0		
13/14	1 1 1 1 1 1 1 1 1 1 1 1 1 0		
1/16	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	16	16
3/16	1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0		
5/16	1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0		
7/16	1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 0		
9/16	1 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0		
11/16	1 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0		
13/16	1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0		
15/16	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		
1/17	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	17	17
2/17	1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0		
3/17	1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0		
4/17	1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 0		
5/17	1 0 0 1 0 0 1 0 0 0 1 0 0 1 0 0 0		
6/17	1 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0		
7/17	1 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 0		
8/17	1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 0		
9/17	1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0		
10/17	1 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 0		
11/17	1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 0		
12/17	1 1 1 0 1 1 0 1 1 1 0 1 1 0 1 1 0		
13/17	1 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0		
14/17	1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0		
15/17	1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 0		
16/17	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		

TABLE 4-2 - Continued

Fraction of spp	Coil Grouping (Sequence of larger and smaller pole-phase groups)	The coil grouping shown repeats (3 times the No. of poles) divided by	Maximum No. of parallel paths = No. of poles divided by
1/19	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	19	19
2/19	1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0		
3/19	1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0		
4/19	1 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0		
5/19	1 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0		
6/19	1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0		
7/19	1 0 1 0 0 1 0 0 1 0 1 0 0 1 0 0 1 0 0		
8/19	1 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 1 0 0		
9/19	1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 0		
10/19	1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0		
11/19	1 1 0 1 0 1 1 0 1 0 1 0 1 1 0 1 0 1 0		
12/19	1 1 0 1 1 0 1 1 0 1 0 1 1 0 1 1 0 1 0		
13/19	1 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0		
14/19	1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 0		
15/19	1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 0		
16/19	1 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0		
17/19	1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 0		
18/19	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		
1/20	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	20	20
3/20	1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0		
7/20	1 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0		
9/20	1 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1 0 0		
11/20	1 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0 1 0		
13/20	1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 0		
17/20	1 1 1 1 1 1 0 1 1 1 1 1 1 0 1 1 1 1 1 0		
19/20	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		

TABLE 4-2 - Continued

Fraction of spp	Coil Grouping (Sequence of larger and smaller pole-phase groups)	The coil grouping shown repeats (3 times the No. of poles) divided by	Maximum No. of parallel paths = No. of poles divided by
1/22	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	22	22
3/22	1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0		
5/22	1 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 0		
7/22	1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0		
9/22	1 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 0		
13/22	1 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 0		
15/22	1 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0		
17/22	1 1 1 1 0 1 1 1 0 1 1 1 1 0 1 1 1 0 1 1 1 0		
19/22	1 1 1 1 1 1 1 0 1 1 1 1 1 1 0 1 1 1 1 1 1 0		
21/22	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		
1/23	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	23	23
2/23	1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0		
3/23	1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0		
4/23	1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0		
5/23	1 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 0		
6/23	1 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0		
7/23	1 0 0 1 0 0 1 0 0 1 0 0 0 1 0 0 1 0 0 1 0 0 0		
8/23	1 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0		
9/23	1 0 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 0		
10/23	1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 1 0 1 0 0		
11/23	1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 0		
12/23	1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0		
13/23	1 1 0 1 0 1 0 1 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0		
14/23	1 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 0		
15/23	1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 0		
16/23	1 1 1 0 1 1 0 1 1 0 1 1 1 0 1 1 0 1 1 0 1 1 0		

TABLE 4-2 - Continued

Fraction of spp	Coil Grouping (Sequence of larger and smaller pole-phase groups)	The coil grouping shown repeats (3 times the No. of poles) divided by	Maximum No. of parallel paths = No. of poles divided by
17/23	1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 0	23	23
18/23	1 1 1 1 0 1 1 1 1 0 1 1 1 0 1 1 1 1 0 1 1 1 0		
19/23	1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0		
20/23	1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 0 1 1 1 1 1 1 0		
21/23	1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 0		
22/23	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		
1/25	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	25	25
2/25	1 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0		
3/25	1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0		
4/25	1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0		
6/25	1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 0		
7/25	1 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0 0		
8/25	1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0		
9/25	1 0 1 0 0 1 0 0 1 0 0 1 0 1 0 0 1 0 0 1 0 0 1 0 0		
11/25	1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 0		
12/25	1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 0		
13/25	1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0		
14/25	1 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0		
16/25	1 1 0 1 1 0 1 1 0 1 1 0 1 0 1 1 0 1 1 0 1 1 0 1 0		
17/25	1 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0		
18/25	1 1 1 0 1 1 1 0 1 1 0 1 1 1 0 1 1 0 1 1 1 0 1 1 0		
19/25	1 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0		
21/25	1 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0		
22/25	1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 0		
23/25	1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 0		
24/25	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		

TABLE 4-2 - Continued

Fraction of spp	Coil Grouping (Sequence of larger and smaller pole-phase groups)	The coil grouping shown repeats (3 times the No. of poles) divided by	Maximum No. of parallel paths = No. of poles divided by
1/26	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	26	26
3/26	1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0		
5/26	1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0		
7/26	1 0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 0 0		
9/26	1 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0		
11/26	1 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 1 0 0		
15/26	1 1 0 1 0 1 1 0 1 0 1 0 1 1 0 1 0 1 0 1 1 0 1 0 1 0		
17/26	1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 0		
19/26	1 1 1 0 1 1 1 0 1 1 1 0 1 1 0 1 1 1 0 1 1 1 0 1 1 0		
21/26	1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0		
23/26	1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 0		
25/26	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		
1/28	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	28	28
3/28	1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0		
5/28	1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0		
9/28	1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0		
11/28	1 0 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 0		
13/28	1 0 1 0 1 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1 0 1 0 1 0 0		
15/28	1 1 0 1 0 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0 1 0 1 0 1 0		
17/28	1 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 0		
19/28	1 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0		
23/28	1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0		
25/28	1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 0		
27/28	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		

TABLE 4-2 - Continued

Fraction of spp	Coil Grouping (Sequence of larger and smaller pole-phase groups)	The coil grouping shown repeats (3 times the No. of poles) divided by	Maximum No. of parallel paths = No. of poles divided by
1/29	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	29	29
2/29	1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0		
3/29	1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0		
4/29	1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0		
5/29	1 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0		
6/29	1 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0		
7/29	1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 0		
8/29	1 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0 0		
9/29	1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0		
10/29	1 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0		
11/29	1 0 1 0 0 1 0 1 0 0 1 0 0 1 0 1 0 0 1 0 0 1 0 1 0 0 1 0 0		
12/29	1 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 0		
13/29	1 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1 0 0		
14/29	1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 0		
15/29	1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0		
16/29	1 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0 1 0		
17/29	1 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 0		
18/29	1 1 0 1 1 0 1 0 1 1 0 1 1 0 1 0 1 1 0 1 1 0 1 0 1 1 0 1 0		
19/29	1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 0		
20/29	1 1 1 0 1 1 0 1 1 0 1 1 0 1 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0		
21/29	1 1 1 0 1 1 1 0 1 1 0 1 1 1 0 1 1 1 0 1 1 0 1 1 1 0 1 1 0		
22/29	1 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0		
23/29	1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 0		
24/29	1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0		
25/29	1 1 1 1 1 1 1 0 1 1 1 1 1 1 0 1 1 1 1 1 1 0 1 1 1 1 1 1 0		
26/29	1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 0		
27/29	1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 0		
28/29	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		

TABLE 4-2 - Continued

Fraction of spp	Coil Grouping (Sequence of larger and smaller pole-phase groups)	The coil grouping shown repeats (3 times the No. of poles) divided by	Maximum No. of parallel paths = No. of poles divided by
1/31	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	31	31
2/31	1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		
3/31	1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0		
4/31	1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0		
5/31	1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0		
6/31	1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0		
7/31	1 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 0		
8/31	1 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0		
9/31	1 0 0 1 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0 1 0 0 0		
10/31	1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0		
11/31	1 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0		
12/31	1 0 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 0		
13/31	1 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 1 0 0		
14/31	1 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1 0 0		
15/31	1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 0		
16/31	1 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1 0		
17/31	1 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0 1 0		
18/31	1 1 0 1 0 1 1 0 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 0 1 1 0 1 0 1 0		
19/31	1 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 0		
20/31	1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 0		
21/31	1 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0 1 1 0		
22/31	1 1 1 0 1 1 0 1 1 1 0 1 1 0 1 1 1 0 1 1 0 1 1 1 0 1 1 0 1 1 0		
23/31	1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 0		
24/31	1 1 1 1 0 1 1 1 0 1 1 1 1 0 1 1 1 0 1 1 1 1 0 1 1 1 0 1 1 1 0		
25/31	1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0		

TABLE 4-2 - Concluded

Fraction of spp	Coil Grouping (Sequence of larger and smaller pole-phase groups)	The coil grouping shown repeats (3 times the No. of poles) divided by	Maximum No. of parallel paths = No. of poles divided by
26/31	1 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0	31	31
27/31	1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 0 1 1 1 1 1 1 0		
28/31	1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 0		
29/31	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		
30/31	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0		

The coil grouping shown applies to the corresponding fraction of spp. In order to find the grouping for spp equal to the fraction plus an integer, add the integer to the values shown under the coil grouping.

Note: The maximum number of parallel paths is half of that shown in the Table when long jumper (T - B) connections are used for windings which have an even denominator of the fraction of spp (See Art. 4-3).

CHAPTER 5

UNBALANCED FRACTIONAL-SLOT LAP WINDINGS (UNBALANCED LAP WINDINGS WITH UNEQUAL COIL GROUPING)

In the foregoing chapter the balanced fractional-slot lap windings have been treated. In these windings, the electromotive forces of all phases have the same magnitude and the angles between consecutive phases are equal. This is not the case with the unbalanced fractional-slot lap windings treated in this chapter. Since an unbalance may produce vibrations and noise or circulating currents which cause additional heat in these windings, they are to be avoided and used only in special cases, as for example, when a winding is to be changed from one number of poles to another number of poles, or from one frequency to another frequency. Unbalanced fractional-slot windings are also used by manufacturers in order to economize on dies; for example, a die with 48 slots is used for 4 and 6 poles, leading to an unbalance at 6 poles in a 3-phase winding.

5-1. Two Kinds of Unbalanced Fractional-slot Lap Windings. Apparently, a winding will be unbalanced when the number of slots is not divisible by the number of phases. However, a winding may be unbalanced also when the number of slots is divisible by the number of phases. The 2 conditions for balance are given in Art. 4-6. Consider a 3-phase, 6-pole winding with 63 slots. For this winding, spp = $\frac{63}{3 \times 6} = \frac{7}{2} = 3\ 1/2$. The denominator of the fraction (1/2) is 2. The first condition for balance requires that the number of poles be divisible by the denominator of the fraction. In this example, the number of poles (6) divided by the denominator (2) of the fraction is equal to 3, and, therefore, the first condition is satisfied. The second condition for balance requires that the denominator of the fraction be not divisible by the number of phases. In this example, the second condition for balance is also satisfied because the denominator 2 is not divisible by the number of phases (3). Therefore, the 3-phase, 6-pole winding with 63 slots is balanced. If the number of slots is 66 instead of 63, the number of slots per pole per phase becomes equal to $\frac{66}{3 \times 6} = \frac{11}{3} = 3\ 2/3$. The denominator of the fraction is now 3. The first condition for balance is again satisfied: $\frac{6}{3} = 2$; the second condition is not satisfied (3 is divisible by 3). This winding is unbalanced despite the fact that the number of slots (66) is divisible by the number of phases (3) and each phase has the same number of coils (22). Consider now the same 3-phase, 6-pole winding with 68 slots. Here, spp $= \frac{68}{3 \times 6} = \frac{34}{9} = 3\ 7/9$, and neither condition of balance is satisfied, as is always the case when the number of slots is not divisible by the number of phases (68 is not divisible by 3).

In the first case of unbalance in which the number of slots and the denominator of the fraction of spp are both divisible by the number of phases, all slots are provided with coils. In the second case of unbalance in which the number of slots is not divisible by the number of phases, some of the coils have to be left out of the winding in order to have the same number of coils in each phase.

In laying out unbalanced fractional-slot windings, the problem is to make the unbalance as small as possible (see Art. 5-7).

5-2. Coil Grouping Tables and How to Use Them. Coil grouping tables are given which show the distribution of the larger and the smaller pole-phase groups around the stator or rotor. The 2 cases of unbalance will be considered separately.

Case (a). The number of slots and the denominator of the fraction are both divisible by the number of phases. For 2-phase windings, Master Table 3-4 gives, in italics, the values of spp corresponding to different numbers of poles and different numbers of slots. For 3-phase windings, the corresponding table is Master Table 3-5. It is evident that for 2-phase windings the denominator of the fraction can be only 2 or a multiple of 2. For 3-phase windings, the denominator of the fraction can be only 3 or a multiple of 3. Table 5-1 for 2-phase windings, and Table 5-2, for 3-phase windings, show the distribution of the larger and the smaller pole-phase groups for the number of poles equal to the denominator of the fraction. For example, for a 2-phase winding, with the denominator of the fraction equal to 2 (spp = 1 1/2, 2 1/2, 3 1/2, etc.), the grouping shown in Table 5-1 represents the grouping for only 2 poles; if the denominator of the fraction is 6 (spp = 1 1/6, 2 1/6, 2 5/6, etc.), then the grouping shown applies to 6 poles. At the same time, Table 5-1 indicates the number of times the coil grouping shown there is to be repeated for windings having a greater number of poles than that indicated by the denominator of the fraction of spp. In the example considered above with the denominator of the fraction equal to 2, the grouping shown in Table 5-1 is to be repeated twice in a 4-pole winding ($\frac{4}{2} = 2$), and 4 times in a 8-pole winding ($\frac{8}{2} = 4$), and so forth. In the example with the denominator of the fraction equal to 6, the grouping shown is to be repeated twice in a 12-pole winding ($\frac{12}{6} = 2$), 8 times in a 48-pole winding ($\frac{48}{6} = 8$), and so forth. Likewise, for a 3-phase winding with the denominator of the fraction equal to 3 (spp = 1 1/3, 2 1/3, 2 2/3, etc.), the grouping shown in Table 5-2 represents the grouping for only 3 poles; if the denominator is 9, then the grouping shown applies to 9 poles. Table 5-2 also indicates the number of times the coil grouping shown there is to be repeated for windings having a greater number of poles than that indicated by the denominator of the fraction of spp. In general, the number of repetitions is equal to the number of poles divided by the denominator of the fraction.

Consider a 2-phase, 8-pole winding with spp = 2 3/4. The numbers opposite to 3/4 in Table 5-1 give the sequence of the larger and the smaller pole-phase groups for 4 poles. The integer of spp, i.e., 2, is to be added to the numbers of the line opposite to 3/4. The grouping thus obtained must be repeated twice since the number of poles (8) divided by the denominator of the fraction (4) equals 2. The coil grouping of the total winding is then

3 3 2 3 3 3 3 2   3 3 2 3 3 3 3 2
A B A B A B A B   A B A B A B A B

The letters A and B indicate the phases to which the individual pole-phase groups are assigned.

As another example, a 3-phase, 12-pole winding with 102 slots will be considered. Master Table 3-5 shows for 12 poles and 102 slots a value of spp equal to 2 5/6. Table 5-2 gives the following sequence of the larger and the smaller pole-phase groups for the fraction 5/6.

1 1 1 0 1 1 1 1 1 1 0 1 1 1 1 1 1 0

Since the integer of spp is equal to 2, this quantity is to be added to all numbers of the grouping. This yields

3 3 3 2 3 3 3 3 3 3 2 3 3 3 3 3 3 2
A C B A C B A C B A C B A C B A C B

The numbers of this series represent the sequence of the pole-phase groups with 2 and 3 single coils respectively for 6 poles only, because the denominator of the fraction is 6. Since the machine has 12 poles, the total winding will consist of $\frac{12}{6} = \frac{\text{No. of poles}}{\text{Denominator of the fraction}} = 2$ repetitions of the grouping shown. The letters A, C, and B indicate the phases to which the individual pole-phase groups are assigned.

The maximum possible number of parallel circuits of the windings considered is apparently equal to the number of repeatable parts of the winding, i.e., to the number of poles divided by the denominator of the fraction. This is the same as for balanced fractional-slot lap windings. If the number of parallel circuits is made smaller than the maximum possible number, the latter must be divisible by the number of parallel paths chosen.

Case (b). The number of slots is not divisible by the number of phases. Tables 5-3 and 5-4 give the corresponding values of spp for different numbers of poles and different numbers of slots for 2-phase and 3-phase windings, respectively. Tables 5-5 and 5-6 show the sequence of the larger and smaller pole-phase groups for different values of spp and different numbers of poles. Add to the ones and zeros the integer of spp in order to get the number of single coils in each group. The pole-phase groups in which a coil is to be left out are indicated by a circle or square around the one or zero. The slots in which a coil side is to be omitted are also given in the Tables (number 1 is assigned to the first slot of phase A).

In order to reduce the unbalance, it is expedient in certain cases to omit the coil within a pole-phase group, i.e., to split a pole-phase group. For this reason, 2 alternatives for the location of the coils to be omitted are given: one without split groups, the other with split groups. The first alternative is indicated by circles around the ones or zeros: the second alternative is indicated by squares around the ones or zeros. The numbers of the slots in which the coil side is to be omitted are given in the Tables for both alternatives. Note that contrary to the case treated under (a), the grouping obtained from Tables 5-5 and 5-6 represents the grouping of the whole winding. Tables

5-5 and 5-6 are layed out for minimum unbalance. The cases in which 2 parallel paths are possible are indicated in these Tables.

Two examples will be considered, the first being a 3-phase, 8-pole machine with 56 slots. Table 5-4 yields for 8 poles and 56 slots a value of spp equal to 2 1/3. For spp equal to 2 1/3 and 8 poles, Table 5-6 indicates the following sequence of the larger and the smaller pole-phase groups.

0 0 1 0 1 0 0 ① 0 1 0 0 0 0 1 0 1 0 0 ① 0 1 0 0

The integer of spp is 2, and, therefore, 2 is to be added to all numbers of the grouping. This gives the following grouping for the whole winding:

2 2 3 2 3 2 2 ③ 2 3 2 2 2 2 3 2 3 2 2 ③ 2 3 2 2
A C B A C B A C B A C B A C B A C B A C B A C B

2 coils are left out, as indicated by the 2 circles, leaving 56-2 = 54 coils, i.e., 18 for each phase. The 2 coils omitted lie in the slots 17 and 47, as shown in Table 5-6. There are 24 pole-phase groups (= No. of poles x No. of phases). Writing the letters A, C, B below or above the pole-phase groups, the phases to which the individual pole-phase groups belong are determined. It can be seen from Table 5-6 that the distribution chosen has a small error in angle and also a small error in magnitude. Two parallel circuits are possible.

As a second example, a 3-phase, 6-pole winding with 40 slots will be considered. Since the number of slots is 40, one coil will have to be left out making the number of coils in each phase equal to 13. Table 5-4 shows that for 6 poles and 40 slots the value of spp is equal to 2 2/9. For spp equal to 2 2/9 and 6 poles, Table 5-6 indicates the following sequence of the larger and smaller pole-phase groups:

$\boxed{\text{①}}$ 0 0 0 1 0 0 0 0 0 1 0 0 0 0 1 0 0 0

Adding the integer of spp 2, the following grouping is obtained for the whole winding:

$\boxed{\text{③}}$ 2 2 2 3 2 2 2 2 3 2 2 2 2 3 2 2 2
A C B A C B A C B A C B A C B A C B

There are 6 x 3 = 18 pole-phase groups. One coil is left out from the first pole-phase group as indicated by the circle and square. As shown in Table 5-6, the slot from which the coil is omitted is either slot 3 or slot 2. In the first case, it is the last coil of the first pole-phase group and the error in angle is 3^{o}. In the second case, it is the second (middle) coil of the first pole-phase group; the pole-phase group is split but the error in angle is only 54'. Only a series connection of the pole-phase groups of each phase is possible in this winding.

In general, the determination of the number of parallel circuits permissible in a winding in which the number of slots is not divisible by the number of phases requires special consideration. This is explained in Art. 5-5. Few groupings permit 2 parallel circuits. Such groupings are indicated in Table 5-6.

It has been pointed out in Chapter 4 that coil grouping tables should be used with care since printing errors are not always avoidable in tables. In Arts. 5-4 and 5-5, simple methods are given which show how to lay out unbalanced windings described under cases (a) and (b) treated above. These methods can be used to check the Tables and also to lay out windings which are not contained in the tables.

5-3. Connection Diagrams and Phase Beginnings.

The Connection Diagrams of the unbalanced fractional-slot lap windings are the same as those of the balanced fractional-slot lap windings (see Art. 4-2) and, therefore, are the same as those of the integral-slot windings treated in detail in Chapter 3. For example, the Connection Diagram of a 3-phase, 6-pole winding with 40 slots, i.e., with spp = 2 2/9, is given by Fig. 3-53, just as the 3-phase, 6-pole integral-slot winding is given by this same diagram. However, the lines which represent the individual pole-phase groups correspond, in the fractional-slot winding, to different numbers of single coils. In the example of the 3-phase, 6-pole winding with 40 slots, these lines represent pole-phase groups with 2 and 3 single coils respectively. The rules which determine the beginnings of the phases for balanced 2-phase fractional-slot lap windings (see Art. 4-9) apply also to unbalanced 2-phase fractional-slot windings.

The starts of any 2 consecutive pole-phase groups can be used as phase beginnings. In general, in 2-phase windings, the beginnings of the phases must lie 1 plus zero or (an even integer x 2) pole-phase groups apart. For example, the beginnings of phases may lie in the starts of pole-phase groups 1 and 2 (= 1 plus 0 pole-phase groups apart) or in the starts of pole-phase groups 1 and 6 (= 1 plus 2 times 2 pole-phase groups apart) or in the starts of the pole-phase groups 1 and 10 and so forth.

The rules which determine the beginnings of the phases of balanced 3-phase fractional-slot windings (see Art. 4-11) apply also to the unbalanced 3-phase fractional-slot windings. The starts of any 3 pole-phase groups which are 2 pole-phase groups apart can be used as beginnings of phases. Therefore, the starts of the pole-phase groups 1, 3, and 5 or the starts of the pole-phase 2, 4, and 6, and so on, can be used as phase beginnings. However, as explained in Art. 4-11, each of the pole-phase groups 1, 3, and 5 (or 2, 4, and 6) can be replaced by one which belongs to the same phase and lies 6 pole-phase groups apart from it. Hence the starts of the groups 1, 9 (= 3 + 6), and 5; or 1, 3, and 11 (= 5 + 6); or 1, 9 (= 3 + 6) and 11 (= 5 + 6); or 1, 9 (= 3 + 6), and 17 (= 11 + 6) can be chosen as phase beginnings. In general, the beginnings of the phases must lie 2 plus zero or (an even integer x 3) pole-phase groups apart.

5-4. Layout of an Unbalanced Fractional-slot Lap Winding When the Number of Slots is Divisible by the Number of Phases (Unbalanced windings of the first kind, case (a), see Arts. 5-1 and 5-2). Let

m = number of phases
N = numerator of spp
d = denominator of spp

For example, in a 2-phase winding with spp = 9/4 = 2 1/4, m = 2, N = 9, and d = 4, and in a 3-phase winding with spp = 8/3 = 2 2/3, m = 3, N = 8, and d = 3.

(a) Write spp in the form $\frac{N}{d}$ where N and d have no common divisor.

(b) Determine the value of D from

$$D = \frac{mNP + m}{d} \qquad (5\text{-}1)$$

where P is the smallest integer, including zero, which makes D and integer.

(c) Write m (i.e., 2 for 2 phases or 3 for 3 phases) series of N numbers each having the difference D. The first series is

$$1, \quad 1 + D, \quad 1 + 2D, \quad 1 + 3D, \quad . \; . \; . \; 1 + (N-1)\,D$$

If one of the numbers of this series becomes larger than N, the latter must be subtracted from the number (see examples). The second series of N numbers is obtained from the first series by adding N to all numbers of the first series. The third series (for 3-phase windings) is obtained from the second by adding N to all numbers of the second series. Thus, the second series is

$$1 + N,\quad 1 + D + N,\quad 1 + 2D + N,$$
$$1 + 3D + N \ . \ . \ . \ 1 + (N-1)\ D + N$$

and the third series (for 3-phase windings only) is

$$1 + 2N,\quad 1 + D + 2N,\quad 1 + 2\ D + 2N,$$
$$1 + 3D + 2N \ . \ . \ . \ 1 + (N-1)\ D + 2N$$

The numbers in these series represent the slots of all phases in d poles.

(d) Divide the slots represented by the m-series into m parts in such a manner that each part, i.e., each phase, contains N slots and that these N slots of each phase are as close to one another as possible. Further, the division of the mN slots among the m phases must give the same number of larger as well as the same number of smaller pole-phase groups for each phase.

(e) The grouping obtained applies to d poles. The total winding consists of as many repetitions of the grouping obtained as there are d poles in the total number of poles, i.e., the number of repetitions is equal to the number of poles divided by d.

(f) The maximum possible number of parallel paths is equal to the number of poles divided by d.

The method described will be demonstrated by 2 examples. Consider first a 2-phase, 4-pole winding in 18 slots. According to Master Table 3-4, spp = 2 1/4 = 9/4. Thus, for this winding m = 2, N = 9, d = 4. From Eq. 5-1.

$$D = \frac{2 \times 9 \times P + 2}{4} = 5 \text{ where } P = 1$$

The first series of N = 9 slots having the difference D is then

$$1,\quad 1 + 5 = 6,\quad 6 + 5 - 9 = 2,\quad 2 + 5 = 7,\quad 7 + 5 - 9 = 3$$
$$3 + 5 = 8,\quad 8 + 5 - 9 = 4,\quad 4 + 5 = 9,\quad 9 + 5 - 9 = 5$$

The second series is obtained from the first by adding N = 9 to all numbers of the first series. Thus, both (m = 2) series are

1 6 2 7 3 | 8 4 9 5
10 15 11 16 | 12 17 13 18 14
A B

The broken line indicates how the mN = 18 slots are divided between the 2 phases A and B. Arranging the slots in the sequence in which they follow each other in the machine, yields

1-2-3 4-5 6-7 8-9 10-11 12-13-14 15-16 17-18
A B A B A B A B

The sequence of the pole-phase groups for d poles and the numbers of single coils in them are, in accordance with Table 5-1,

3 2 2 2 2 3 2 2
A B A B A B A B

Each phase, for d = 4 poles, has 1 group with 3 single coils, and 3 groups with 2 single coils. Since the number of poles is equal to 4 and also d is equal to 4, the grouping obtained has 4/4 = 1 repetition, i.e., the grouping obtained represents the total winding. Parallel circuits are not possible in this winding.

As a second example, a 3-phase, 18-pole winding with 114 slots will be treated. From Master Table 3-5, spp = 2 1/9 = $\frac{19}{9}$. Therefore, m = 3, N = 19, d = 9. From Eq. 5-1,

$$D = \frac{3 \times 19 \times P + 3}{9} = 13 \text{ with } P = 2$$

The first series of N = 19 slots is

1, 1 + 13 = 14, 14 + 13 - 19 = 8, 8 + 13 - 19 = 2,
2 + 13 = 15, 15 + 13 - 19 = 9, 9 + 13 - 19 = 3,
3 + 13 = 16, and so on.

Since m = 3, there are 3 series. The second series is obtained from the first by adding N = 19 to all numbers of the first series. The third series is obtained from the second series by adding N = 19 to all numbers of the second series. The 3 series are:

1 14 8 2 15 9 3 | 16 10 4 17 11 5 | 18 12 6 19 13 7
20 33 27 21 34 28 | 22 35 29 23 36 30 24 | 37 31 25 38 32 26
39 52 46 40 53 47 | 41 54 48 42 55 49 | 43 56 50 44 57 51 45
A C B

The broken lines indicate the division of the mN = 57 slots among the 3 phases. The coil grouping for d = 9 poles is in accordance with Table 5-2

3 2 2 2 2 2 2 2 2 2 3 2 2 2 2 2 2 2 2 3 2 2 2 2 2 2

A C B A C B A C B A C B A C B A C B A C B A C B A C B

Each phase, for d = 9 poles, has 1 pole-phase group with 3 single coils and 8 pole-phase groups with 2 single coils.

Since the number of poles (= 18) divided by d (= 9) is 2, the total winding consists of 2 repetitions of the coil grouping obtained. The total number of pole-phase groups is the same as for integral-slot windings, namely, equal to the number of poles times the number of phases. In this case, there are 18 x 3 = 54 pole-phase groups. The number of poles divided by d is equal to 2. Hence, the maximum number of parallel paths is 2.

5-5. Layout of an Unbalanced Fractional-slot Lap Winding When the Number of Slots is Not Divisible by the Number of Phases.

(Unbalanced windings of the second kind, case (b), see Arts. 5-1 and 5-2.) As in Art. 5-4, let

m = number of phases
N = numerator of spp
d = denominator of spp

For example, in a 2-phase winding with spp = $\frac{29}{12}$ = 2 5/12, m = 2, N = 29, and d = 12.

(a) Write spp in the form $\frac{N}{d}$ where N and d have no common divisor.

(b) Determine the value of D from

$$D = \frac{mNP + m}{d} \tag{5-2}$$

where P is the smallest integer, including zero, which makes D an integer.

(c) Determine the largest common divisor t of the number of poles and the number of slots. For example, for a 2-phase, 6-pole winding in 29 slots, this common divisor t is equal to 1, and for a 3-phase, 6-pole winding in 38 slots, the largest common divisor t is equal to 2 since the number of poles (6) is divisible by 2, and the number of slots (38) is also divisible by 2.

(d) Write t series of N numbers each having the difference D. The first series is

1, 1 + D, 1 + 2D, 1 + 3D, . . . 1 + (N-1) D

If one of the numbers of the series becomes larger than N, the latter must be subtracted from the number (see examples). The second series of N numbers is obtained from the first series by adding N to all numbers of the first series. The third series is obtained from the second series by adding N to all numbers of the second series, and so on. Thus, the second series is

$$1 + N,\quad 1 + D + N,\quad 1 + 2D + N,$$
$$1 + 3D + N. \;.\; .\; 1 + (N-1)D + N$$

and the third series is

$$1 + 2N,\quad 1 + D + 2N,\quad 1 + 2D + 2N,$$
$$1 + 3D + 2N. \;.\; .1 + (N-1)D + N$$

and so on. The numbers of the t series obtained in this manner represent the slots of the total winding.

(e) Divide the slots represented by the t series into m parts in such a manner that each part, i.e., each phase, contains the same number of slots and that the slots of each phase are as close to one another as possible. Since the number of slots is not divisible by the number of phases, an equal number of slots in each phase can be achieved only when a certain number of coils (which is usually smaller than the number of phases m) is left out. The division of t x N slots among the m phases must give the same number of larger as well as the same number of smaller pole-phase groups for each phase.

The method described will be demonstrated by 2 examples. Consider first a 2-phase, 6-pole winding in 33 slots, i.e., spp $= \frac{33}{2 \times 6} = \frac{11}{4} = 2\ 3/4$. Thus, for this winding, $m = 2$, $N = 11$, $d = 4$. From Eq. 5-2

$$D = \frac{2 \times 11 \times P + 2}{4} = 6 \text{ with } P = 1$$

The largest common divisor of the number of poles (6) and the number of slots (33) is equal to 3 ($t = 3$). Hence, 3 series of $N = 11$ numbers have to be written, the difference between 2 consecutive numbers in each series being $D = 6$ and the difference between the numbers of 2 consecutive series being $N = 11$. The first series of $N = 11$ slots is

$$1,\quad 1 + 6 = 7,\quad 7 + 6 - 11 = 2,\quad 2 + 6 = 8,$$
$$8 + 6 - 11 = 3,\quad 3 + 6 = 9,\quad 9 + 6 - 11 = 4,$$
$$4 + 6 = 10,\quad 10 + 6 - 11 = 5,\quad 5 + 6 = 11,$$
$$11 + 6 - 11 = 6$$

or

1 7 2 8 3 9 4 10 5 11 6

The second series is obtained by adding N = 11 to all figures of the first series, and the third series is obtained by adding N = 11 to all figures of the second series. Hence, the t = 3 series are

1	7	2	8	3	9	4	10	5	11	6	
12	18	13	19	14	20	15	21	16	22	17	
23	29	24	30	25	31	26	32	27	33	28	(L)
		A						B			

The broken line indicates how the t x N = 33 slots are divided between the 2 phases A and B. Arranging the slots in the sequence in which they follow each other in the machine,

1 2 3	4 5 6	7 8 9	10 11	12 13 14	15 16 17	18 19	20 21 22
A	B	A	B	A	B	A	B

23 24 25	26 27 28	29 30 31	32 33
A	B	A	B

The sequence of the pole-phase groups and the number of single coils in them are

3	3	③	2	3	3	2	3	3	3	3	2
A	B	A	B	A	B	A	B	A	B	A	B

It can be seen that 17 slots have been assigned to phase A and 16 slots to phase B. In order to make the number of slots the same in both phases one coil is to be left out in phase A. The pole-phase group of phase A in which the coil is left out is indicated by a circle. As Table 5-5 shows, the error in angle is 2^{o} 3' and the error in magnitude is negligible if the coil is omitted from slot 9, i.e., if the third coil of the second pole-phase group of phase A is left out. If the coil is omitted from slot 2, i.e., if the first pole-phase group of phase A is split, then the error in angle decreases to 1^{o} 1' but the error in magnitude increases to 2.3%.

Phase A, as well as phase B, has 4 pole-phase groups with 3 single coils and 2 pole-phase groups with 2 single coils. The distribution obtained represents the total winding. It is in accordance with Table 5-5.

As a second example, a 3-phase, 4-pole winding in 44 slots will be considered. From Table 5-4, spp = 3 2/3 = 11/3. Therefore, m = 3, N = 11, d = 3. From Eq. 5-2

$$D = \frac{3 \times 11 \times P + 3}{3} = 1 \text{ with } P = 0$$

The largest common divisor of the number of poles (4) and the number of slots (44) is 4 (t = 4). Hence, 4 series of 11 numbers each have to be written. Since D = 1, the 4 series are represented by the consecutive numbers 1 to 44. The t = 4 series are

1	2	3	4	5	6	7	8	9	10	11	
12	13	14	15	16	17	18	19	20	21	22	(M)
23	24	25	26	27	28	29	30	31	32	33	
34	35	36	37	38	39	40	41	42	43	44	
	A				C				B		

The broken lines indicate how the t x N = 44 slots are divided among the 3 phases A, C, and B. The sequence of the pole-phase groups and the numbers of single coils in them are

4 3 4 ④ 4 3 4 3 4 3 4 ④
A C B A C B A C B A C B

It can be seen that 15 slots have been assigned to phase A, 14 slots to phase C, and 15 slots to phase B. In order to make the number of coils the same for all phases, 2 coils are to be left out, one in phase A and one in phase B. The pole-phase groups in which the coils are to be omitted are indicated by circles. Table 5-6 shows that the slots in which the coils are to be left out are 15 and 41. With 2 coils left out, each phase consists of 2 pole-phase groups with 4 single coils and 2 pole-phase groups with 3 single coils. The distribution obtained represents the total winding. It is in accordance with Table 5-6. The error in angle is $+1^{\circ}\,39'$ and that in magnitude is 0.45%.

An inspection of the t series with N slots each makes it possible to determine whether and how many parallel paths are possible. The maximum possible number of parallel paths in each phase is equal to t (= largest common divisor of the number of poles and the number of slots). However, t parallel paths in each phase are permissible only when the slots assigned to the phase lie in the t series one above the other. Consider the slot chart (L) of the first example. The slots assigned to phase A are 1, 7, 2, 8, 3, 9 in the first series; 12, 18, 13, 19, 14 in the second series; and 23, 29, 24, 30, 25, 31 in the third series. The t = 3 slots 1-12-23, 7-18-29, 2-13-24, 8-19-30, and 3-14-25 lie one above the other but there are no t slots in phase A below slot 9. Therefore, 3 parallel paths are not possible in phase A. Also, phase B does not satisfy the condition for 3 parallel paths. The winding of the first example, if distributed according to chart (L), must be connected in series. However, leaving out 3 coils instead of 1, it becomes possible to make t = 3 parallel paths. Leaving out, for example, the coils 9, 20, and 31, the distribution is

1	7	2	8	3	⑨	4	10	5	11	6	
12	18	13	19	14	⑳	15	21	16	22	17	
23	29	24	30	25	㉛	26	32	27	33	28	(L')
		A						B			

The coils of each phase lying in the horizontal (in the same series) must be connected in series. So, in phase A, the coils 1-2-3-7-8, the coils 12-13-14-18-19, and the coils 23-24-25-29-30 must be connected in series, respectively. Since now the coils of the t = 3 series lie one above the other, they can be connected in parallel, i.e., the coil-sequence 1-2-3-7-8 can be connected in parallel with the coil-sequence 12-13-14-18-19 and with coil-sequence 23-24-25-29-30. The same applies to phase B. In this phase, the coils 4-5-6-10-11, 15-16-17-21-22, and 26-27-28-32-33 must be connected in series, respectively, and the 3 coil rows can be connected in parallel.

The coil grouping which corresponds to the slot chart (L') is

3	3	③	2	3	3	③	2	3	3	③	2
A	B	A	B	A	B	A	B	A	B	A	B

The error of the distribution (L') is zero in magnitude and 8^{o} 11' in angle. Leaving out coils from the slots 2, 13, and 24, i.e., splitting 3 pole-phase groups of phase A, makes the error in angle only 1^{o} 38' but increases the error in magnitude to 5.45%. Both distributions should be avoided (see Art. 5-7).

t is the maximum possible number of parallels. Depending upon the coil distribution, it is possible to make less than t parallels. In this case, t must be divisible by the number of parallels chosen. Considering again the first example, t is equal to 3. Since 3 is divisible only by 3 and 1, either 3 parallel paths or series connection is possible.

Consider now the winding of the second example (3 phases, 4 poles, 44 slots, spp = 3 2/3). Since for this winding t = 4, theoretically 4 or 2 parallel paths are possible. An inspection of the chart (M) shows that, with the coil distribution given, t = 4 parallels are not possible. Consider, for example, phase C; the coil 37 has no corresponding coils in the other 3 series, since coils 4, 15, and 26 belong to phase A. However, 2 parallel paths are possible if the coil distribution is as follows

1	2	3	4	5	6	7	8	9	10	11	
12	13	14	15	16	17	18	⑲	20	21	22	(M')
23	24	25	26	27	28	29	30	31	32	33	
34	35	36	37	38	39	40	㊶	42	43	44	
		A			C				B		

and coils 19 and 41 are left out. In phase A, the coils 1-2-3-4-12-13-14 and the coils 23-24-25-26-34-35-36 are to be connected in series, respectively, and both coil rows then connected in parallel. In phase C, the coils 5-6-7-15-16-17-18 and the coils 27-28-29-37-38-39-40 are to be connected in series, respectively, and both coil rows in parallel. In phase B, the coils 8-9-10-11-20-21-22 and the coils 30-31-32-33-42-43-44 are to be connected in series, respectively, and both coil rows in parallel.

The error of the distribution (M') is 0 in magnitude and $5^{\circ}\ 30'$ in angle. Leaving out coils from slots 20 and 42 instead of 19 and 41, i.e., splitting 2 pole-phase groups in phase B makes the error in angle $3^{\circ}\ 54'$ and the error in magnitude 0.97%. With respect to unbalance, the arrangement with split pole-phase groups is preferable.

Note, that coil rows connected in parallel must have symmetrical positions in the slot chart. Consider again phase A of slot chart (M'). It is seen that there are 2 symmetrical groups of coils, namely, the coils 1, 2, 3, 4, 12, 13, 14 and the coils 23, 24, 25, 26, 34, 35, 36. Such coil rows can be connected in parallel. The same applies to phases C and B.

It has been shown for the winding of the first example (2 phases, 6 poles, 33 slots) that, by leaving out 3 coils instead of one, 3 parallel paths can be made. The parallel paths have been achieved in this case at the expense of the number of active coils of the machine and at the expense of the magnitude of unbalance which became larger. In the second example, of the 3-phase, 4-pole winding, the 2 parallel paths have been achieved at the expense of the magnitude of unbalance. In unbalanced windings from which coils are omitted, the distribution of the slots among the phases established in the slot charts (L, M, L' and M'), and the number and location of the omitted coils influence the unbalance and the possible number of parallel paths. The minimum errors in the angles are achieved when the left-out coils lie as close as possible to the line of symmetry of the phase. However, for this location of the omitted coils, the error in magnitude becomes maximum. When parallel paths are necessary, this can be achieved in certain cases at the expense of the number of active coils and of the magnitude of unbalance; in other cases, at the expense of the magnitude of unbalance. The coil groupings in Tables 5-5 and 5-6 are based upon a minimum of unbalance. The magnitude of the unbalance and the possible number of parallel paths are shown in these Tables. Since the location of the omitted coils influences the grouping and the magnitude of the unbalance, the numbers of the slots in which a coil is to be left out are given in Tables 5-5 and 5-6. Note that number 1 is assigned to the first slot of phase A (see Art. 5-2, case b).

5-6. Simplification of the Coil Grouping Tables of the Unbalanced Fractional-slot Lap Windings.

As in the balanced fractional-slot lap windings, the sequence of the larger and smaller pole-phase groups is determined by the fraction of spp only,when S/m is an integer. For this reason, the coil groupings given in Tables 5-1 and 5-2 show only the sequence of larger and smaller pole-phase groups. In order to obtain the number of single coils in the individual pole-phase groups, the integer of spp is to be added to the numbers of the coil grouping tables, as has been explained in Art. 5-2; when S/m is not an integer, the sequence of the larger and smaller pole-phase groups depends upon the layout of the winding and the number and location of the omitted coils. The digits 1 and 0 in Table 5-5 and 5-6 means larger and smaller pole-phase groups, just as in the Table 5-1; however the distribution of the groups is not determined here by the fraction of spp. As in the Tables 5-1 and 5-2, the integer of spp is to be added to 1 or 0, in order to find the number of single coils in the group.

5-7. Permissible Degree of Unbalance. An unbalance of 2 to 3 degrees between the phase voltages or of 2% to 3% in the magnitude of the voltages will not be harmful in a 2-phase machine or in a star-connected 3-phase machine. Delta connection of unbalanced windings must be avoided. No unbalance, neither in the angle nor in the magnitude of the voltages, is permissible between winding parts connected in parallel (see also Art. 5-5).

In windings with the number of slots divisible by the number of phases, the unbalance is larger, the smaller the numerator of spp, written in the form $\frac{N}{d}$. For example, a winding with spp = 4/3 will have a larger unbalance than a winding with spp = 5/3, because, in the former, the numerator N = 4 is smaller than the numerator N = 5 in the latter. This is explained in Appendix 4.

Fig. 5-1 shows the error in phase angle for 2-phase windings with a number of slots divisible by 2. The unbalance is due to the fact that the denominator d of spp is divisible by 2 (= number of phases). In 2-phase windings of this kind, the voltages are always equal. It can be seen that the error in the phase angle rapidly decreases with increasing values of the numerator N of spp.

Table 5-7 shows the errors in voltage and phase angle for 3-phase windings with a number of slots divisible by 3. As for 2-phase windings, the unbalance is due to the fact that d is divisible by the number of phases 3. It can be seen that the error in voltage is in general small. The error in angle depends upon the magnitude of N. N = 7 already yields an error in angle which is smaller than 3°. Fig. 5-2 shows the larger errors in angle, i.e., for phase B.

The errors in angle and voltage for 2-phase and 3-phase windings with the number of slots not divisible by the number of phases are given in Tables 5-5 and 5-6. Here the magnitude of the errors depends upon the layout of the winding and upon the number and location of the slots from which coils are omitted. The method of calculating the unbalance is given in Appendix 4.

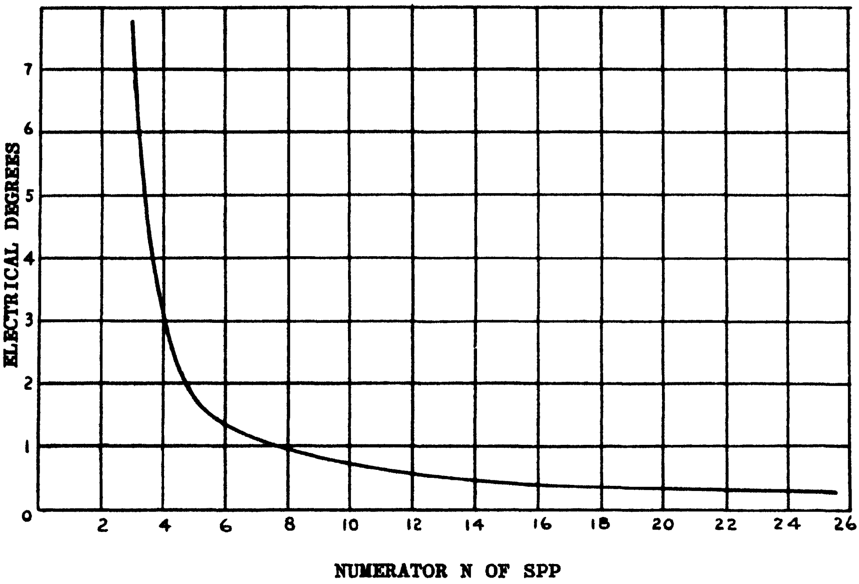


Fig. 5-1. Error in angle of 2-phase windings with a number of slots divisible by 2.

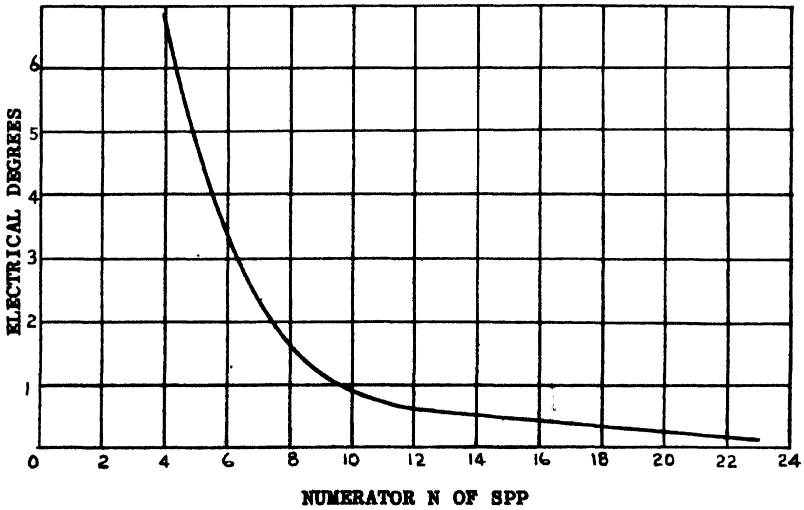


Fig. 5-2. Error in angle of 3-phase windings with a number of slots divisible by 3.

TABLE 5-1 - COIL GROUPING OF UNBALANCED 2-PHASE WINDINGS WITH A NUMBER OF SLOTS DIVISIBLE BY THE NUMBER OF PHASES

Fraction of spp	Coil Grouping (Sequence of the larger and smaller pole-phase groups)	Total No. of Repetitions of the grouping = No. of poles divided by	Maximum No. of Parallel paths = No. of poles divided by
1/2	1 0 0 1	2	2
1/4	1 0 0 0 0 1 0 0	4	4
3/4	1 1 0 1 1 1 1 0		
1/6	1 0 0 0 0 0 1 0 0 0 0 0	6	6
5/6	1 1 1 1 0 1 1 1 1 1 1 0		
1/8	1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0	8	8
3/8	1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 0		
5/8	1 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0		
7/8	1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 0		
1/10	1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0	10	10
3/10	1 0 0 1 0 0 1 0 0 0 1 0 0 1 0 0 0 1 0 0		
7/10	1 1 0 1 1 1 0 1 1 0 1 1 1 0 1 1 0 1 1 0		
9/10	1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 0		

The coil grouping shown applies to the corresponding fraction of spp. In order to find the grouping for spp equal to the fraction plus an integer, add the integer to the values shown under coil grouping.

TABLE 5-2 - COIL GROUPING OF UNBALANCED 3-PHASE WINDINGS WITH A NUMBER OF SLOTS DIVISIBLE BY THE NUMBER OF PHASES

Fraction of spp	Coil Grouping (Sequence of the larger and smaller pole-phase groups)	Total No. of Repetitions of the grouping = No. of poles divided by	Maximum No. of parallel paths = No. of poles divided by
1/3	1 0 0 0 0 1 0 1 0	3	3
2/3	1 0 1 0 1 1 1 1 0		
1/6	1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0	6	6
5/6	1 1 1 0 1 1 1 1 1 1 0 1 1 1 1 1 1 0		
1/9	1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0	9	9
2/9	1 0 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 0		
4/9	1 0 1 0 0 1 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 1 0 1 0 0		
5/9	1 1 0 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 1 0 1 0 1 1 0 1 0		
7/9	1 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 1 0 1 1 1 1 0		
8/9	1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 0		
1/12	1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0	12	12
5/12	1 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 1 0 1 0 0		
7/12	1 1 0 1 0 1 0 1 1 0 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 0 1 0		
11/12	1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 0		

The coil grouping shown applies to the corresponding fraction of spp. In order to find the grouping for spp equal to the fraction plus an integer, add the integer to the values shown under coil grouping.

TABLE 5-3 - SPP FOR 2-PHASE WINDINGS WITH A NUMBER OF SLOTS NOT DIVISIBLE BY THE NUMBER OF PHASES

No. of Poles	2	4	6	8	10	12	14
No. of Pole-phase Groups	4	8	12	16	20	24	28
No. of Slots	SPP						
11	2 3/4	1 3/8					
13	3 1/4	1 5/8	1 1/12				
15	3 3/4	1 7/8	1 1/4				
17	4 1/4	2 1/8	1 5/12	1 1/16			
19	4 3/4	2 3/8	1 7/12	1 3/16			
21	5 1/4	2 5/8	1 3/4	1 5/16			
23	5 3/4	2 7/8	1 11/12	1 7/16	1 3/20		
25	6 1/4	3 1/8	2 1/12	1 9/16	1 1/4	1 1/24	
27		3 3/8	2 1/4	1 11/16	1 7/20	1 1/8	
29		3 5/8	2 5/12	1 13/16	1 9/20	1 5/24	
31		3 7/8	2 7/12	1 15/16	1 11/20	1 7/24	1 3/28
33		4 1/8	2 3/4	2 1/16	1 13/20	1 3/8	1 5/28
35		4 3/8	2 11/12	2 3/16	1 3/4	1 11/24	1 1/4
37		4 5/8	3 1/12	2 5/16	1 17/20	1 13/24	1 9/28
39		4 7/8	3 1/4	2 7/16	1 19/20	1 5/8	1 11/28
41		5 1/8	3 5/12	2 9/16	2 1/20	1 17/24	1 13/28
43		5 3/8	3 7/12	2 11/16	2 3/20	1 19/24	1 15/28
45			3 3/4	2 13/16	2 1/4	1 7/8	1 17/28
47			3 11/12	2 15/16	2 7/20	1 23/24	1 19/28
49			4 1/12	3 1/16	2 9/20	2 1/24	1 3/4
51			4 1/4	3 3/16	2 11/20	2 1/8	1 23/28
53			4 5/12	3 5/16	2 13/20	2 5/24	1 25/28
55			4 7/12	3 7/16	2 3/4	2 7/24	1 27/28
57			4 3/4	3 9/16	2 17/20	2 3/8	2 1/28
59			4 11/12	3 11/16	2 19/20	2 11/24	2 3/28
61				3 13/16	3 1/20	2 13/24	2 5/28
63				3 15/16	3 3/20	2 5/8	2 7/28
65				4 1/16	3 1/4	2 17/24	2 9/28
67				4 3/16	3 7/20	2 19/24	2 11/28
69					3 9/20	2 7/8	2 13/28
71					3 11/20	2 23/24	2 15/28
73					3 13/20	3 1/24	2 17/28
75					3 3/4	3 1/8	2 19/28
77					3 17/20	3 5/24	2 3/4
79					3 19/20	3 7/24	2 23/28
81					4 1/20	3 3/8	2 25/28
83					4 3/20	3 11/24	2 27/28
85						3 13/24	3 1/28
87						3 5/8	3 3/28
89						3 17/24	3 5/28
91						3 19/24	3 7/28
95						3 23/24	3 11/28
97						4 1/24	3 13/28
99							3 15/28
101							3 17/28
105							3 3/4
107							3 23/28
109							3 25/28
111							3 27/28
113							4 1/28

TABLE 5-4 - SPP FOR 3-PHASE WINDINGS WITH A NUMBER OF SLOTS NOT DIVISIBLE BY THE NUMBER OF PHASES

No. of Poles	2	4	6	8	10	12	14	16	18	20	22
No. of Pole-phase Groups	6	12	18	24	30	36	42	48	54	60	66
No. of Slots	SPP										
8	1 1/3										
10	1 2/3										
14	2 1/3										
16	2 2/3	1 1/3									
20	3 1/3	1 2/3	1 1/9								
22	3 2/3	1 5/6	1 2/9								
26	4 1/3	2 1/6	1 4/9								
28	4 2/3	2 1/3	1 5/9								
32		2 2/3	1 7/9	1 1/3							
34		2 5/6	1 8/9	1 5/12							
38		3 1/6	2 1/9	1 7/12							
40		3 1/3	2 2/9	1 2/3	1 1/3	1 1/9					
44		3 2/3	2 4/9	1 5/6	1 7/15	1 2/9					
46		3 5/6	2 5/9	1 11/12	1 8/15	1 5/18					
50		4 1/6	2 7/9	2 1/12	1 2/3	1 7/18					
52		4 1/3	2 8/9	2 1/6	1 11/15	1 4/9					
56		4 2/3	3 1/9	2 1/3	1 13/15	1 5/9	1 1/3				
58			3 2/9	2 5/12	1 14/15	1 11/18	1 8/21				
62			3 4/9	2 7/12	2 1/15	1 13/18	1 10/21				
64			3 5/9	2 2/3	2 2/15	1 7/9	1 11/21	1 1/3			
68			3 7/9	2 5/6	2 4/15	1 8/9	1 13/21	1 5/12	1 7/27		
70			3 8/9	2 11/12	2 1/3	1 17/18	1 2/3	1 11/24	1 8/27		
74			4 1/9	3 1/12	2 7/15	2 1/18	1 16/21	1 13/24	1 10/27		
76			4 2/9	3 1/6	2 8/15	2 1/9	1 17/21	1 7/12	1 11/27		
80			4 4/9	3 1/3	2 2/3	2 2/9	1 19/21	1 2/3	1 13/27	1 1/3	
82			4 5/9	3 5/12	2 11/15	2 5/18	1 20/21	1 17/24	1 14/27	1 11/30	
86			4 8/9	3 7/12	2 13/15	2 7/18	2 1/21	1 19/24	1 16/27	1 13/30	
88				3 2/3	2 14/15	2 4/9	2 2/21	1 5/6	1 17/27	1 7/15	1 1/3
92				3 5/6	3 1/15	2 5/9	2 4/21	1 11/12	1 19/27	1 8/15	1 13/33
98				4 1/12	3 4/15	2 13/18	2 1/3	2 1/24	1 22/27	1 19/30	1 16/33
100				4 1/6	3 1/3	2 7/9	2 8/21	2 1/12	1 23/27	1 2/3	1 17/33
104				4 1/3	3 7/15	2 8/9	2 10/21	2 1/6	1 25/27	1 11/15	1 19/33
110				4 7/12	3 2/3	3 1/18	2 13/21	2 7/24	2 1/27	1 5/6	1 2/3
112				4 2/3	3 11/15	3 1/9	2 2/3	2 1/3	2 2/27	1 13/15	1 23/33
116					3 13/15	3 2/9	2 16/21	2 5/12	2 4/27	1 14/15	1 25/33
124					4 2/15	3 4/9	2 20/21	2 7/12	2 8/27	2 1/15	1 29/33
128					4 4/15	3 5/9	3 1/21	2 2/3	2 10/27	2 2/15	1 31/33
130					4 1/3	3 11/18	3 2/21	2 17/24	2 11/27	2 1/6	1 32/33
136					4 8/15	3 7/9	3 5/21	2 5/6	2 14/27	2 4/15	2 2/33
140					4 2/3	3 8/9	3 1/3	2 11/12	2 16/27	2 1/3	2 4/33
148						4 1/9	3 11/21	3 1/12	2 20/27	2 7/15	2 8/33
152						4 2/9	3 13/21	3 1/6	2 22/27	2 8/15	2 10/33
154						4 5/18	3 2/3	3 5/24	2 23/27	2 17/30	2 1/3
160						4 4/9	3 17/21	3 1/3	2 26/27	2 2/3	2 14/33
164						4 5/9	3 19/21	3 5/12	3 1/27	2 11/15	2 16/33
172						4 7/9	4 2/21	3 7/12	3 5/27	2 13/15	2 20/33
176						4 8/9	4 4/21	3 2/3	3 7/27	2 14/15	2 2/3
182							4 1/3	3 19/24	3 10/27	3 1/30	2 25/33
196							4 2/3	4 1/12	3 17/27	3 4/15	2 32/33
200								4 1/6	3 19/27	3 1/3	3 1/33
208								4 1/3	3 23/27	3 7/15	3 5/33
220								4 7/12	4 2/27	3 2/3	3 1/3
224								4 2/3	4 4/27	3 11/15	3 13/33
242									4 13/27	4 1/30	3 2/3
260									4 17/27	4 1/3	3 31/33
280										4 2/3	4 8/33
286											4 1/3
308											4 2/3

TABLE 5-5

COIL GROUPING AND UNBALANCE IN MAGNITUDE AND PHASE ANGLE OF 2-PHASE WINDINGS WITH A NUMBER OF SLOTS NOT DIVISIBLE BY THE NUMBER OF PHASES

spp	No. of Poles	No. of Slots	No. of Parallel Circuits Possible	COIL GROUPING (SEQUENCE OF LARGER AND SMALLER POLE-PHASE GROUPS)	POLE-PHASE GROUP NOT SPLIT				POLE-PHASE GROUP SPLIT			
					UNBALANCE				UNBALANCE			
					Magnitude (Percent)	Phase Angle (Electrical Degrees)	Distribution Factor	Coil Side Omitted in Slot Number	Magnitude (Percent)	Phase Angle (Electrical Degrees)	Distribution Factor	Coil Side Omitted in Slot Number
1 7/8	4	15	1	1 1 1 1 1 1 ① 0	4.38	1°	0.893	13	...	...	...	...
1 11/12	6	23	1	① 1 1 1 1 1 1 1 1 1 1 0	2.70	21'	0.896	2	...	...	...	...
1 11/16	8	27	1	1 1 ① 0 1 1 $\boxed{0}$ 1 1 0 1 1 0 1 1 0	0.00	3°20'	0.908	6	1.99	30'	0.898	12*
1 13/16	8	29	1	1 1 1 1 ① 0 1 1 1 1 $\boxed{0}$ 1 1 1 1 0	0.00	3° 6'	0.908	10	2.43	0'	0.898	20*
1 15/16	8	31	1	1 1 1 1 1 1 1 1 1 1 1 1 1 1 ① 0	2.27	12'	0.898	29	...	...	...	...
2 1/4	2	9	1	$\boxed{\textcircled{1}}$ 0 0 0	0.00	10°	0.922	3	8.02	0°	0.887	2
2/3/4	2	11	1	1 1 $\boxed{\textcircled{1}}$ 0	0.00	8°11'	0.920	9	6.52	1°38'	0.890	8
2 1/8	4	17	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 0 0	0.00	5°17'	0.913	3	4.00	0°	0.895	2
2 3/8	4	19	1	$\boxed{\textcircled{1}}$ 0 1 0 0 1 0 0	0.00	4°44'	0.912	1	3.42	38'	0.896	2
2 5/8	4	21	1	1 1 0 1 ① 0 $\boxed{1}$ 0	0.00	4°17'	0.912	14	3.29	0°	0.897	18
2 7/8	4	23	1	1 $\boxed{1}$ 1 1 1 ① 0 1	0.00	3°55'	0.910	18	3.09	26'	0.898	5
2 1/12	6	25	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 0 0 0 0 0 0	0.00	3°36'	0.908	3	2.29	0°	0.898	2
2 1/4	6	27	1	$\boxed{\textcircled{1}}$ 0 0 0 0 1 0 0 1 0 0 0	0.00	2°18'	0.927	3	2.61	48'	0.898	2

2 5/12	6	29	1	1 0 $\boxed{1}$ 0 ① 0 0 1 0 1 0 0	0.00	3° 6'	0.908	13	2.44	0'	0.898	7
2 7/12	6	31	1	1 1 0 1 0 1 ① 0 1 0 $\boxed{1}$ 0	0.00	2°54'	0.908	19	2.28	12'	0.898	28
2 3/4	6	33	1	$\boxed{1}$ 1 ① 0 1 1 0 1 1 1 1 0	0.00	2° 3'	0.919	9	2.34	1° 1'	0.896	2
2 11/12	6	35	1	1 1 1 1 $\boxed{1}$ 1 1 1 1 1 ① 0	0.00	2°34'	0.908	33	1.94	3'	0.900	14
2 1/16	8	33	1	$\boxed{①}$ 0 0 0 0 0 0 0 0 0 0 0	0.00	2°44'	0.908	3	2.28	0'	0.896	2
2 3/16	8	35	1	$\boxed{①}$ 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0	0.00	2°34'	0.908	1	1.94	7'	0.900	2
2 5/16	8	37	1	① 0 0 1 0 0 $\boxed{1}$ 0 0 1 0 0 0 1 0 0	0.00	2°26'	0.908	1	1.43	0'	0.900	16
2 7/16	8	39	1	1 0 $\boxed{1}$ 0 1 0 ① 0 0 1 0 1 0 1 0 0	0.00	2°18'	0.908	18	1.51	2'	0.903	7
2 9/16	8	41	1	1 1 0 1 0 1 0 1 ① 0 1 0 $\boxed{1}$ 0 1 0	0.00	2°12'	0.903	24	1.39	0'	0.897	33
2 11/16	8	43	1	1 1 ① 0 $\boxed{1}$ 1 0 1 1 0 1 1 0 1 1 0	0.00	2° 6'	0.900	9	1.16	6'	0.894	13
2 13/16	8	45	1	1 1 $\boxed{1}$ 1 ① 0 1 1 1 1 0 1 1 1 1 0	0.00	2° 0'	0.904	15	1.26	0'	0.903	8
2 15/16	8	47	1	1 1 1 1 1 1 $\boxed{1}$ 1 1 1 1 1 1 1 ① 0	0.00	1°55'	0.906	45	1.46	6'	0.897	20
3 1/4	2	13	1	① 0 $\boxed{0}$ 0	0.00	6°55'	0.917	4	5.08	0'	0.895	9
3 1/8	4	25	1	① 0 0 0 $\boxed{0}$ 0 0 0	0.00	3°36'	0.908	4	2.75	0'	0.896	15
3 3/8	4	27	1	1 0 ① 0 0 1 $\boxed{0}$ 0	0.00	3°20'	0.908	11	1.94	30'	0.898	23
3 1/12	6	37	1	① 0 0 0 0 0 $\boxed{0}$ 0 0 0 0 0	0.00	2°26'	0.907	4	1.77	0'	0.898	21
3 1/4	6	39	1	① 0 $\boxed{0}$ 0 0 1 0 0 1 0 0 0	0.00	1°53'	0.918	4	1.75	19'	0.898	9
3 1/16	8	49	1	① 0 0 0 0 0 0 0 $\boxed{0}$ 0 0 0 0 0 0 0	0.00	1°49'	0.906	4	1.15	0'	0.900	27
3 3/16	8	51	1	1 0 $\boxed{0}$ 0 0 1 0 0 0 0 ① 0 0 0 0 0	0.00	1°46'	0.903	36	1.31	0'	0.894	9

* = A complete small pole-phase group is omitted.
○ = Coil left out at the beginning or end of a pole-phase group.
□ = Coil left out within a pole-phase group (group split).

TABLE 5-6

COIL GROUPING AND UNBALANCE IN MAGNITUDE AND PHASE ANGLE FOR 3-PHASE WINDINGS WITH A NUMBER OF SLOTS NOT DIVISIBLE BY THE NUMBER OF PHASES.

spp	No. of Poles	No. of Slots	No. of Parallel Circuits Possible	COIL GROUPING (SEQUENCE OF LARGER AND SMALLER POLE-PHASE GROUPS)	POLE-PHASE GROUP NOT SPLIT				POLE-PHASE GROUP SPLIT			
					UNBALANCE				UNBALANCE			
					Magnitude (Percent)	Phase Angle (Electrical Degrees) *	Distribution Factor	Coil Side Omitted in Slot Number	Magnitude (Percent)	Phase Angle (Electrical Degrees)	Distribution Factor	Coil Side Omitted in Slot Number
2 1/3	2	14	1	① 0 0 0 ① 0	2.72	+4° 18' +8° 35' -4° 17'	0.960	3 and 12	...	....	....	...
	4	28	1	0 ① 0 1 0 0 0 1 0 0 0 1	0.23	+3° 4' + 17' +2° 47'	0.956	3	...	....	....	...
	4	28	1	0 1 0 1 ⓪ 0 0 1 0 0 0 1	2.67	+ 8' + 17' - 9'	0.938	11	...	....	....	...
	8	56	2	0 0 1 0 1 0 0 ① 0 1 0 0 0 0 1 0 1 0 0 ① 0 1 0 0	0.88	+ 6' + 6' 0'	0.950	17 and 47	...	....	....	...
	10	70	1	1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 1 0 0 0 1 0 0 0 1 0 ① 0	0.91	+ 36' -1° 5' +1° 41'	0.953	66	...	....	....	...
	14	98	2	0 0 1 0 0 1 0 1 0 0 1 0 0 ① 0 1 0 0 1 0 0 0 0 1 0 0 1 0 1 0 0 1 0 0 ① 0 1 0 0 1 0 0	0.66	- 26' - 54' + 28'	0.950	31 and 82	...	....	....	...
	16	112	1	1 0 0 0 1 0 0 0 1 0 0 1 0 0 1 0 1 0 1 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 1 0 0 0 1 0 1 0 ① 0 0 1 0 0	0.57	- 8' -1° 34' +1° 26'	0.950	101	...	....	....	...
	16	112	2	0 0 1 0 0 1 0 0 ① 0 1 0 0 1 0 ① 0 0 1 0 0 1 0 0 0 0 1 0 0 1 0 0 ① 0 1 0 0 1 0 ① 0 0 1 0 0 1 0 0	0.87	+ 8' + 18' - 10'	0.953	19,38, 75 and 94	...	....	....	...
	20	140	1	1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 0 ① 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 ① 0 0	0.68	- 39' -1° 11' + 32'	0.950	47 and 136	...	....	....	...
	20	140	1	① ⓪ 0 0 1 0 0 0 ① 0 0 1 0 1 0 1 0 0 0 ① 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 ① 0 0	1.14	+ 8' + 17' - 9'	0.952	3,4,19, 47 and 136	...	....	....	...
	22	154	1	1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 1 0 0 0 1 0 0 0 1 0 ① 0	0.62	- 22' -1° 44' +1° 22'	0.948	150	...	....	....	...

2 1/3	22	154	2	1 0 0 1 0 0 1 0 0 ① 0 0 0 1 0 0 1 0 0 1 0 0 0 ① 0 0 1 0 0 1 0 0 1 1 0 0 1 0 0 1 0 0 ① 0 0 0 1 0 0 1 0 0 1 0 0 0 ① 0 0 1 0 0 1 0 0 1	0.63	- 26' - 41' + 15'	0.953	24,54 101 and 131	...	....	....	...
2 2/3	2	16	1	1 0 1 0 ① 1	3.15	-1° 36' +1° 36' -3° 12'	0.945	13	...	....	....	...
	4	32	1	1 0 1 ① 1 0 1 0 1 0 1 ①	0.63	+ 48' +1° 35' - 47'	0.953	11 and 30	...	....	....	...
	8	64	1	1 1 0 1 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 1 0 ① 1	1.80	-1° 1' - 55' - 6'	0.946	61	...	....	....	...
	10	80	1	0 1 1 1 0 ① 1 1 0 1 1 0 1 0 1 0 1 1 0 1 1 ① 0 1 1 1 0 1 0 1	0.81	- 12' - 28' + 16'	0.950	14 and 59	...	....	....	...
	14	112	1	0 1 1 1 0 1 1 1 0 1 0 1 0 1 1 1 0 1 1 1 0 ① 1 0 0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1	1.13	+ 17' -1° 8' +1° 25'	0.954	59	...	....	....	...
	14	112	2	0 1 1 0 1 1 ① 0 1 1 0 1 1 0 ① 1 1 0 1 1 0 0 1 1 0 1 1 ① 0 1 1 0 1 1 0 ① 1 1 0 1 1 0	1.15	+ 5' + 9' - 4'	0.958	19,38, 75 and 94	...	....	....	...
	16	128	1	0 1 1 1 0 ① 1 1 0 1 1 0 1 1 0 1 0 1 0 ① 1 0 1 1 0 1 1 1 0 1 1 1 0 1 0 1 1 1 0 1 0 1 0 1 1 0 1 1	1.00	- 26' - 55' + 29'	0.956	14 and 51	...	....	....	...
	16	128	1	0 1 1 1 0 ① 1 1 0 1 1 0 1 1 0 ① 0 ① 0 ① 1 0 ① 1 0 1 1 1 0 1 1 1 0 1 0 1 1 1 0 1 0 1 0 1 1 0 1 1	1.53	- 6' + 21' - 27'	0.954	14,43, 46,51, and 61	...	....	....	...
	20	160	1	0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 1 0 1 0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 0 1 ① 0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1	0.89	-1° 20' -1° 22' + 2'	0.956	110	...	....	....	...
	20	160	2	0 1 1 0 1 1 0 1 1 ① 0 1 1 0 1 1 0 1 1 0 ① 1 1 0 1 1 0 1 1 0 0 1 1 0 1 1 0 1 1 ① 0 1 1 0 1 1 0 1 1 0 ① 1 1 0 1 1 0 1 1 0	1.20	- 19' - 22' + 3'	0.954	27,54, 107 and 134	...	....	....	...
	22	176	1	0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 0 1 1 0 1 1 1 0 1 ① 1 0 1 1 0 1 0 1 0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 0 1 ① 1 0 1 1 1 0 1 0 1	0.90	- 32' -1° 7' + 35'	0.953	75 and 150	...	....	....	...
	22	176	1	0 1 1 ① 0 ① 1 ① 0 1 1 0 1 0 1 0 1 1 0 1 1 0 1 1 1 0 1 ① 1 0 1 1 0 1 0 1 0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 0 1 ① 1 0 1 1 1 0 1 0 1	1.46	+ 7' - 13' + 20'	0.954	11,14, 20,75 and 150	...	....	....	...
3 1/3	2	20	1	① 0 0 0 0 ①	1.37	+3° +6° -3°	0.966	4 and 17	...	....	....	...
	4	40	1	0 ① 0 1 0 0 0 1 0 0 0 1	0.00	+2° 25' + 33' +1° 52'	0.954	4	...	....	....	...
	4	40	1	0 1 0 1 ⓪ 0 0 1 0 0 0 1	1.13	+ 33' + 33' 0'	0.950	15	...	....	....	...

TABLE 5-6 - Continued

COIL GROUPING AND UNBALANCE IN MAGNITUDE AND PHASE ANGLE FOR 3-PHASE WINDINGS WITH A NUMBER OF SLOTS NOT DIVISIBLE BY THE NUMBER OF PHASES.

spp	No. of Poles	No. of Slots	No. of Parallel Circuits Possible	COIL GROUPING (SEQUENCE OF LARGER AND SMALLER POLE-PHASE GROUPS)	POLE-PHASE GROUP NOT SPLIT				POLE-PHASE GROUP SPLIT			
					UNBALANCE				UNBALANCE			
					Magnitude (Percent)	Phase Angle (Electrical Degrees) *	Distribution Factor	Coil Side Omitted in Slot Number	Magnitude (Percent)	Phase Angle (Electrical Degrees)	Distribution Factor	Coil Side Omitted in Slot Number
3 1/3	8	80	1	0 ① 0 1 0 0 0 1 0 0 0 1 0 ① 0 1 0 0 0 1 0 0 0 1	0.80	+ 19' + 34' - 15'	0.954	4 and 47	...	....	....	...
	10	100	1	1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 1 ⓪ 0 0 1 0 0 0 1 0 1 0	0.32	+ 3' - 26' + 29'	0.952	65	...	....	....	...
	14	140	1	1 0 0 0 1 0 0 0 1 0 0 ① 1 0 0 0 1 0 0 0 1 0 ① 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0	0.91	0' - 7' + 7'	0.954	37 and 74	...	....	....	...
	16	160	1	1 0 0 0 1 0 0 0 1 0 0 1 0 0 1 0 1 0 1 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 1 0 0 0 1 0 1 0 ① 0 0 1 0 0	0.79	+ 13' - 43' + 56'	0.954	144	...	....	....	...
	20	200	1	1 0 0 0 1 0 0 0 1 0 0 1 0 ① 0 1 0 0 0 1 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 ① 0 0	0.79	- 12' - 29' + 17'	0.954	47 and 194	...	....	....	...
	22	220	1	1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 1 0 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 0 1 0 0 0 1 0 0 1 0 1 0 1 0 0 1 0 0 0 1 0 0 0 1 0 ① 0	0.86	- 3' - 49' + 46'	0.954	214	...	....	....	...
3 2/3	2	22	1	① 0 1 1 1 0	0.00	+5° 28' +1° 32' +3° 56'	0.957	4	...	....	....	...
	4	44	1	1 0 1 ① 1 0 1 0 1 0 1 ①	0.45	+ 50' +1° 39' - 49'	0.952	15 and 41	...	....	....	...
	8	88	1	1 1 0 1 1 0 1 1 0 1 0 1 1 0 1 0 1 1 0 1 1 0 ① 1	1.45	- 46' - 24' - 22'	0.952	84	...	....	....	...
	10	110	1	0 1 1 1 0 ① 1 1 0 1 1 0 1 0 1 0 1 1 0 1 1 ① 0 1 1 1 0 1 0 1	0.58	0' 0' 0'	0.954	19 and 81	...	....	....	...
	14	154	1	0 1 1 1 0 1 1 1 0 1 0 1 0 1 1 1 0 1 1 1 0 ① 1 0 0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1	0.62	+ 41' - 40' +1° 21'	0.955	81	...	....	....	...

3 2/3	16	176	1	0 1 1 1 0 ① 1 1 0 1 1 0 1 1 0 1 0 1 0 ① 1 0 1 1 0 1 1 1 0 1 1 1 0 1 0 1 1 1 0 1 0 1 0 1 1 0 1 1	0.45	- 11' - 24' + 13'	0.954	19 and 70	...	....	....	...
	20	220	1	0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 1 0 1 0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 0 1 ① 0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1	0.57	- 53' - 44' - 9'	0.954	151	...	....	....	...
	20	220	2	0 1 1 0 1 1 0 1 1 ① 0 1 1 0 1 1 0 1 1 0 ① 1 1 0 1 1 0 1 1 0 0 1 1 0 1 1 0 1 1 ① 0 1 1 0 1 1 0 1 1 0 ① 1 1 0 1 1 0 1 1 0	0.65	- 2' + 1' - 3'	0.954	37,74, 147 and 184	...	....	....	...
	22	242	1	0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 0 1 1 0 1 1 1 0 1 ① 1 0 1 1 0 1 0 1 0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 0 1 ① 1 0 1 1 1 0 1 0 1	0.72	- 16' - 35' + 19'	0.954	103 and 206	...	....	....	...
	22	242	1	0 1 1 ① ⓪ ① 1 1 0 1 1 0 1 0 1 0 1 1 0 1 1 0 1 1 1 0 1 ① 1 0 1 1 0 1 0 1 0 1 1 1 0 1 1 1 0 1 1 0 1 0 1 0 1 1 0 1 ① 1 0 1 1 1 0 1 0 1	0.33	+ 16' + 6' + 10'	0.954	15,16, 19,103, and 206	...	....	....	...
2 1/6	2	13	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0	0.00	+9° 14' +4° 37' +4° 37'	0.965	3	3.88	+2° 18' -2° 19' +4° 37'	0.953	2
	4	26	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 0 0 ① 0 0 0	0.91	+2° 19' +4° 37' -2° 18'	0.963	3 and 18	2.46	-1° 9' +1° 9' -2° 18'	0.954	2 and 18
	8	52	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0	0.92	+1° 54' + 31' +1° 23'	0.955	3	2.64	+ 16' -1° 7' +1° 23'	0.945	2
	10	65	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 ① 0 0 0 0 0 1 0 0 0	0.50	+ 41' +1° 22' - 41'	0.958	3 and 44	1.73	- 46' - 5' - 41'	0.956	2 and 44
	14	91	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0	0.35	+ 59' + 1' + 58'	0.957	3	1.04	+ 4' - 54' + 58'	0.956	2
	16	104	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 ① 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0	0.61	+ 18' + 36' - 18'	0.955	3 and 70	0.61	- 37' - 19' - 18'	0.954	2 and 70
2 5/6	2	17	1	$\boxed{1}$ 1 1 ① 0 $\boxed{\textcircled{1}}$	0.00	+3° 31' +7° 3' -3° 32'	0.966	12 and 15	2.07	-2° 50' + 42' -3° 32'	0.959	2 and 15
	4	34	1	$\boxed{1}$ 1 1 ① 1 0 1 1 1 1 0 1	0.28	+3° 31' +1° 17' +2° 14'	0.958	12	0.91	+ 37' -1° 37' +2° 14'	0.956	2
	8	68	1	$\boxed{1}$ 1 1 ① 1 0 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 $\boxed{\textcircled{1}}$	0.47	+ 40' +1° 22' - 42'	0.958	12 and 66	0.47	- 45' - 3' - 42'	0.956	2 and 66
	10	85	1	$\boxed{1}$ 1 1 ① 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1	0.00	+1° 16' + 17' + 59'	0.953	12	0.00	+ 9' - 50' + 59'	0.953	2
	14	119	1	$\boxed{1}$ 1 1 ① 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 1 0 1 $\boxed{\textcircled{1}}$	0.27	+ 14' + 37' - 23'	0.955	12 and 117	0.27	- 31' - 8' - 23'	0.955	2 and 117

TABLE 5-6 - Continued

COIL GROUPING AND UNBALANCE IN MAGNITUDE AND PHASE ANGLE FOR 3-PHASE WINDINGS WITH A NUMBER OF SLOTS NOT DIVISIBLE BY THE NUMBER OF PHASES.

spp	No. of Poles	No. of Slots	No. of Parallel Circuits Possible	COIL GROUPING (SEQUENCE OF LARGER AND SMALLER POLE-PHASE GROUPS)	POLE PHASE GROUP NOT SPLIT				POLE-PHASE GROUP SPLIT			
					UNBALANCE				UNBALANCE			
					Magnitude (Percent)	Phase Angle (Electrical Degrees) *	Distribution Factor	Coil Side Omitted in Slot Number	Magnitude (Percent)	Phase Angle (Electrical Degrees)	Distribution Factor	Coil Side Omitted in Slot Number
2 5/6	16	136	1	$\boxed{1}$ 1 1 ① 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 0 1 1	0.00	+ 48' 0 + 48'	0.958	12	0.46	0 - 48' + 48'	0.957	2
3 1/6	2	19	1	① 0 0 $\boxed{0}$ 0 0	0.00	+6° 19' +3° 10' +3° 9'	0.960	4	2.25	+1° 35' -1° 34' +3° 9'	0.953	12
	4	38	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 0 0 $\boxed{\textcircled{1}}$ 0 0 0	0.17	+1° 35' +3° 10' -1° 35'	0.960	4 and 26	1.22	-1° 35' + 0' -1° 35'	0.955	2 and 26
	8	76	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0 1 0 0 0	0.42	+1° 23' + 38' + 45'	0.955	4	0.42	- 1' - 46' + 45'	0.954	2
	10	95	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 $\boxed{\textcircled{1}}$ 0 0 0	0.34	+ 31' +1° 4' - 33'	0.957	4 and 83	0.34	- 39' - 6' - 33'	0.956	2 and 83
	14	133	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0	0.24	+ 51' + 19' - 32'	0.957	4	0.24	- 2' - 34' + 32'	0.956	2
	16	152	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 $\boxed{\textcircled{1}}$ 0 0 0	0.00	+ 14' + 31' - 17'	0.955	4 and 140	0.00	- 28' - 11' - 17'	0.955	2 and 140
3 5/6	2	23	1	1 1 1 $\boxed{\textcircled{1}}$ 0 $\boxed{\textcircled{1}}$	0.00	+2° 36' +5° 13' -2° 37'	0.963	16 and 20	1.72	-1° 52' + 45' -2° 37'	0.958	14 and 20
	4	46	1	1 1 1 $\boxed{\textcircled{1}}$ 0 1 1 1 1 1 1 0	0.00	+2° 36' +1° 3' +1° 33'	0.957	16	0.70	+ 31' -1° 2' +1° 33'	0.955	14
	8	92	1	1 1 1 $\boxed{\textcircled{1}}$ 1 0 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 ①	0.35	+ 31' +1° 3' - 32'	0.956	16 and 89	0.35	- 32' 0' - 32'	0.955	14 and 89
	10	115	1	1 1 1 $\boxed{\textcircled{1}}$ 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1	0.00	+1° 2' + 12' + 50'	0.955	16	0.28	+ 13' - 37' + 50'	0.954	14

3 5/6	14	161	1	1 1 1 $\boxed{\textcircled{1}}$ 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 0 0 1 $\boxed{\textcircled{1}}$	0.00	+ 15' + 28' - 13'	0.956	16 and 158	0.20	- 18' - 5' - 13'	0.955	14 and 158
	16	184	1	1 1 1 $\boxed{\textcircled{1}}$ 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 0 1 1 1 1 1 0 1 1	0.00	+ 35' + 10' + 25'	0.955	16	0.00	+ 5' - 30' + 25'	0.955	14
2 1/9	6	38	1	$\boxed{\textcircled{1}}$ 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0	0.17	+1° 35' +3° 10' -1° 35'	0.958	3	1.48	- 48' + 47' -1° 35'	0.955	2
	12	76	1	1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 $\boxed{1}$ 0 0 0 0 0 ⓪ 0 0 1 0 0 0 0 0 0 0	0.62	- 34' + 5' - 39'	0.956	55	1.04	+ 6' - 11' - 17'	0.955	42
2 2/9	6	40	1	$\boxed{\textcircled{1}}$ 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0	0.00	+3° +1° 8' +1° 52'	0.954	3	0.48	+ 56' - 56' +1° 52'	0.952	2
	12	80	1	1 0 0 0 1 0 0 0 0 1 0 0 0 0 $\boxed{\textcircled{1}}$ 0 0 0 0 $\boxed{\textcircled{1}}$ 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0	0.00	+ 31' +1° 2' - 31'	0.953	32 and 43	0.40	+ 31' + 4' + 27'	0.952	33 and 43
2 4/9	6	44	1	$\boxed{1}$ 0 1 0 1 0 ① 0 0 1 0 1 0 $\boxed{\textcircled{1}}$ 0 0 1 0	0.30	+1° 22' +2° 44' -1° 22'	0.957	18 and 35	0.97	- 58' + 24' -1° 22'	0.955	2 and 35
	12	88	1	$\boxed{1}$ 0 1 0 1 0 ① 0 0 1 0 1 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 1 0	0.00	+1° 10' + 24' + 46'	0.955	18	0.36	+ 5' - 41' + 46'	0.954	2
2 5/9	6	46	1	$\boxed{\textcircled{1}}$ 1 0 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0	0.00	-1° 5' -2° 36' +1° 31'	0.955	1	0.70	+ 31' -1° +1° 31'	0.952	2
	12	92	1	1 1 0 1 0 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 $\boxed{\textcircled{1}}$ 1 0 1 0 1 0 $\boxed{1}$ 0 1 ① 0 1 0 1 0	0.00	+ 31' +1° - 29'	0.953	52 and 80	0.18	- 32' - 3' - 27'	0.953	52 and 71
2 7/9	6	50	1	1 1 1 ① 0 1 $\boxed{1}$ 1 0 1 1 1 0 1 1 1 $\boxed{\textcircled{1}}$ 0	0.20	+1° 12' +2° 24' -1° 12'	0.958	12 and 48	0.78	- 36' + 36' -1° 12'	0.954	19 and 48
	12	100	1	1 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 1 0 1 1 1 0 1 $\boxed{1}$ 1 0 ① 1 1 1 0 1 1 1 0 1	0.00	- 40' + 23' -1° 3'	0.955	73	0.16	- 40' - 27' - 13'	0.955	66
2 8/9	6	52	1	1 1 1 $\boxed{1}$ 1 1 ① 0 1 1 1 1 1 1 1 0 1 1	0.00	+2° 18' + 57' +1° 21'	0.955	21	1.85	+ 20' - 41' +1° 1'	0.950	11
	12	104	1	1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 0 1 1 $\boxed{1}$ 1 1 1 0 $\boxed{\textcircled{1}}$ ① 1 1 1 1 1 1 0 1 1	0.62	+ 29' +1° 1' - 32'	0.953	73 and 76	0.62	+ 39' + 8' + 31'	0.952	60 and 73
3 1/9	6	56	1	① 0 0 0 0 0 $\boxed{0}$ 0 0 0 $\boxed{\textcircled{1}}$ 0 0 0 0 0 0 0	0.35	+1° 4' +2° 8' -1° 4'	0.954	4 and 35	0.81	- 43' + 22' -1° 5'	0.952	21 and 35
	12	112	1	1 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 ① 0 0 0 0 0 0 0 0 1 0 0 0 0 0 $\boxed{0}$ 0	0.00	+1° 0' + 29' + 31'	0.950	60	0.11	+ 18' + 29' - 11'	0.950	108

TABLE 5-6 - Concluded

COIL GROUPING AND UNBALANCE IN MAGNITUDE AND PHASE ANGLE FOR 3-PHASE WINDINGS WITH A NUMBER OF SLOTS NOT DIVISIBLE BY THE NUMBER OF PHASES.

spp	No. of Poles	No. of Slots	No. of Parallel Circuits Possible	COIL GROUPING (SEQUENCE OF LARGER AND SMALLER POLE-PHASE GROUPS)	POLE-PHASE GROUP NOT SPLIT				POLE-PHASE GROUP SPLIT			
					UNBALANCE				UNBALANCE			
					Magnitude (Percent)	Phase Angle (Electrical Degrees) *	Distribution Factor	Coil Side Omitted in Slot Number	Magnitude (Percent)	Phase Angle (Electrical Degrees)	Distribution Factor	Coil Side Omitted in Slot Number
3 2/9	6	58	1	$\textcircled{1}$ 0 0 $\boxed{0}$ 1 0 0 0 0 1 0 0 0 0 1 0 0 0	0.00	+2° 4' + 52' +1° 12'	0.955	4	0.52	+ 26' - 46' +1° 12'	0.953	12
	12	116	1	1 0 0 0 1 0 0 0 0 1 0 $\boxed{0}$ 0 0 $\textcircled{1}$ 0 0 0 0 $\boxed{\textcircled{1}}$ 0 0 0 1 0 0 0 0 1 0 0 0 1 0 0 0	0.00	+ 28' + 54' - 26'	0.955	46 and 62	0.55	+ 28' + 3' + 25'	0.954	38 and 62
3 4/9	6	62	1	1 0 1 0 1 0 $\boxed{\textcircled{1}}$ 0 0 1 0 1 0 $\boxed{\textcircled{1}}$ 0 0 1 0	0.42	+ 58' +1° 56' - 58'	0.957	25 and 49	0.68	- 46' + 12' - 58'	0.955	23 and 49
	12	124	1	1 0 1 0 1 0 1 0 0 1 0 1 $\boxed{0}$ 1 0 $\textcircled{1}$ 0 0 1 0 1 0 1 0 0 1 0 1 0 1 0 0 1 0 1 0	0.00	+ 52' + 20' + 32'	0.955	56	0.26	+ 11' - 21' + 32'	0.955	44
3 5/9	6	64	1	1 1 0 $\textcircled{1}$ 0 1 $\boxed{0}$ 1 0 1 0 1 1 0 1 0 1 0	0.00	+1° 40' + 49' + 51'	0.952	15	0.50	+ 19' - 32' + 51'	0.950	24
	12	128	1	1 1 0 1 0 1 0 1 0 1 0 1 0 1 1 0 1 0 1 0 $\boxed{\textcircled{1}}$ 1 0 1 0 1 0 1 0 1 $\textcircled{1}$ 0 1 $\boxed{0}$ 1 0	0.00	+ 26' + 43' - 17'	0.952	72 and 111	0.00	- 17' + 0' - 17'	0.952	72 and 120
3 7/9	6	68	1	1 1 1 $\boxed{\textcircled{1}}$ 0 1 1 1 0 1 1 1 0 1 1 1 $\boxed{\textcircled{1}}$ 0	0.48	+ 53' +1° 46' - 53'	0.952	16 and 65	0.48	- 34' + 19' - 53'	0.950	14 and 65
	12	136	1	1 1 1 1 0 1 1 1 0 1 1 1 0 1 1 1 1 0 1 1 1 0 1 1 1 0 $\boxed{\textcircled{1}}$ 1 1 1 0 1 1 1 0 1	0.00	- 28' + 22' - 50'	0.952	99	0.00	- 28' - 21' - 7'	0.952	101
3 8/9	6	70	1	1 1 1 1 1 1 1 0 1 1 1 1 1 1 $\boxed{1}$ 0 1 $\textcircled{1}$	0.00	- 58' + 45' -1° 43'	0.953	67	1.39	- 58' - 22' - 36'	0.950	57
	12	140	1	1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 0 $\boxed{\textcircled{1}}$ $\boxed{\textcircled{1}}$ 1 1 1 1 1 1 0 1 1	0.00	+ 25' + 46' - 21'	0.956	98 and 102	0.68	+ 25' + 8' + 17'	0.954	98 and 104

* = First angle between A and C, second between A and B, third between B and C.
○ = Coil left out at the beginning or end of a pole-phase group.
□ = Coil left out within a pole-phase group (group split).

TABLE 5-7 - UNBALANCE OF 3-PHASE WINDINGS WITH A NUMBER OF SLOTS DIVISIBLE BY 3

Numerator of SPP Written in the Form N/d Where N and d Have No Common Divisor	Difference Between the Magnitudes of Phase C and Phase A in % of Phase A (Phase B is equal to Phase A)	Error in angle (in Electrical Degrees) Between Phase A and Phase:	
		C	B
4	-2.08%	-3°18'	-6°36'
5	-3.09%	-2°17'	-4°34'
7	-0.86%	-1°05'	-2°10'
8	-1.06%	- 52'	-1°44'
10	-0.45%	- 32'	-1°04'
11	-0.58%	- 28'	- 56'
13	-0.28%	- 18'	- 36'
17	-0.20%	- 12"	- 24'
19	-0.14%	- 9'	- 18'
23	-0.10%	- 6'	- 12'

CHAPTER 6

INTEGRAL-SLOT AND (INTEGRAL + 1/2)-SLOT 3-PHASE WAVE WINDINGS

6-1. General Features of the Wave Winding. Back Pitch, Front Pitch, Winding Pitch, Reversing Jumper. In contrast to the lap winding which has coils with knuckles at both ends (Fig. 1-13), the wave winding has coils with knuckles at one end only. At the other or lead end, the coil ends are bent away from the center line of the coil (Fig. 1-14). A certain number of such coils, specifically, as many as there are pole pairs, are connected in series and go around the rotor (or stator) core, returning to a point near to the starting point. Such a leg or wave is called a series of coils. A single series of coils for a 6-pole machine is shown in Fig. 6-1.

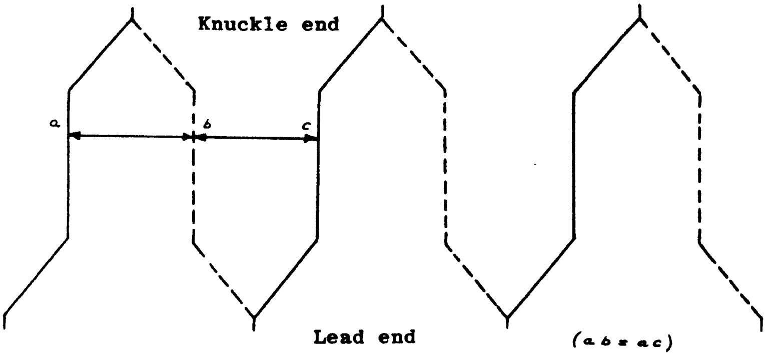


Fig. 6-1. One coil series of a 6-pole winding

Each phase contains several series of coils. It will be shown later that the number of coil series depends upon the number of slots per pole per phase.

The wave winding is a 2-layer winding, similar to the lap winding. Therefore, if conductor (a) in Fig. 6-1 is an upper conductor, conductor (b) is a lower conductor, (c) is again an upper conductor, and so on. The distance (a) to (b) in Fig. 6-1 fixes the width of all coils of the winding. This is the back pitch of the winding and it can be expressed in either of two common ways. If (a) is in slot 1 and (b) is in slot 10, the back pitch may be expressed as 1 and 10, or it can be expressed as 9 slot pitches (10 - 1 = 9). The distance (b) to (c) between the conductors of two consecutive coils is the front pitch and this also can be expressed in terms similar to the back pitch. The distance (a) to (c), i.e., the sum of the back pitch and front pitch, is the winding pitch. The back pitch is the distance between upper and lower conductor, or vice versa, of the same coil. The winding pitch is the distance between 2 consecutive upper or lower conductors.

The wave winding is used mainly in rotors of induction motors and is usually 3-phase. For this reason, only the 3-phase windings will be treated in this book. Furthermore, this chapter will be limited to the windings for which spp is an integer or an (integer + 1/2) while the other fractional-slot wave windings, balanced and unbalanced, will be treated in Chapters 7 and 8.

When spp = integer, then the

back pitch = coil width = 3 X spp

front pitch = back pitch (6-1)

When spp = (integer + 1/2), then the

back pitch = coil width = (3 X spp) + 1/2

front pitch = back pitch - 1

For example, a 3-phase winding with spp = 3 has a back pitch and a front pitch of 9 slot pitches; a 3-phase winding with spp = 3 1/2 has a back pitch of (3 x 3 1/2) + 1/2 = 11 slot pitches and a front pitch of 11 - 1 = 10 slot pitches. The winding pitch is equal to 9 + 9 = 18 slot pitches for spp = 3, and to 11 + 10 = 21 slot pitches for spp = 3 1/2. Note that the winding pitch is equal to the number of slots under 2 poles.

The back pitch as well as the front pitch does not depend upon the number of poles. The pitches depend exclusively upon the value of spp. For example, a 4-pole and a 6-pole winding with spp = 3 have the same back and front pitches. This makes it possible to classify the wave windings according to number of slots per pole per phase, just as it has been done with the lap windings.

The winding of each phase consists of 2 parts connected by a connector. One part is wound clockwise; the other part is wound counter-clockwise, or vice versa. Because both parts run in opposite directions, the connector is called a reversing jumper. In the integral-slot winding, each part consists of as many coil series (Fig. 6-1) as there are slots per pole per phase. In the (integral + 1/2)-slot winding, one part consists of (spp + 1/2) coil series, the other part of (spp - 1/2) coil series.

Since the coil width is the same for all coils, the back pitch is also the same for all coils. This is not the case with the front pitch. There are always a certain number of abnormal front pitches which are shorter or longer than the normal. It depends upon the way in which the coil series of each winding part are connected together, whether the abnormal front pitches are shorter or longer than the normal front pitches. This is explained in detail in the next article.

6-2. Different Ways of Starting and Winding the 3 Phases. Retrogressive and Progressive Windings, Short-pitch and Long-pitch Coils. The coils used for wave windings can be left-hand (Fig. 6-2) or right-hand (Fig. 6-3) coils. In both cases, upper or lower conductors can be chosen as the starts of the 3 phases; in both cases the first part of each phase can be wound clockwise and the second part counter-clockwise or vice versa. This gives a certain variety in carrying out the winding. Further variations are given by the way in which the coil series of each part are connected together. This can be seen best in Fig. 6-4 in which the 3 coil series of one part of phase A of a 6-pole machine with spp = 3 are shown. The slot groups assigned to phase A are:

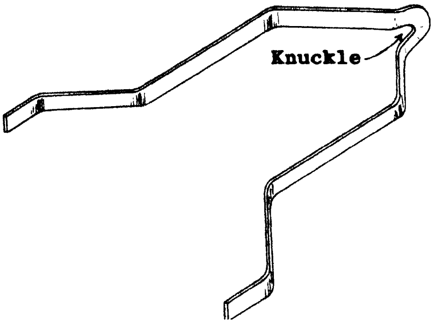


Fig. 6-2a. Left-hand full-turn coil for a wave winding

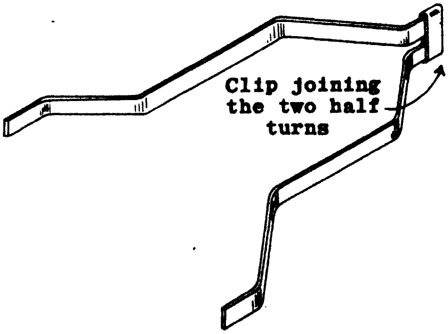


Fig. 6-2b. Left-hand half-turn coil for a wave winding

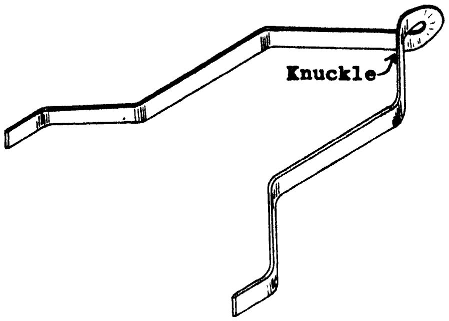


Fig. 6-3a. Right-hand full-turn coil for a wave winding

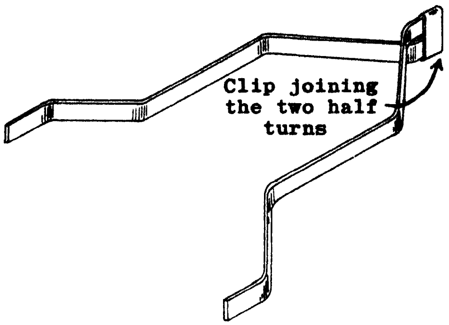


Fig. 6-3b. Right-hand half-turn coil for a wave winding

1-2-3 10-11-12 19-20-21 28-29-30 37-38-39 46-47-48

This leaves between 2 consecutive groups 6 slots for the phases C and B (3 for each phase). Since spp = 3, the back pitch and front pitch (= spp x No. of phases) are equal to 3 x 3 = 9, respectively, and the winding pitch (= back pitch + front pitch) is equal to 18, i.e., if the upper conductor of a coil lies in slot 1, its lower conductor must lie in slot (1 + 9) = 10, and the next consecutive upper conductors of the series to which the considered coil belongs must lie in the slots (1 + 18) = 19 and 19 + 18 = 37.

Let the start of phase A be in the upper conductor 1 of the coil series b_1-e_1 (see Fig. 6-4). If the end of this series, e_1, is connected with the beginning of the next series b_2 which lies in slot 2, i.e., ahead of the beginning of the first series, the winding is progressive. On the other hand, if the end of a

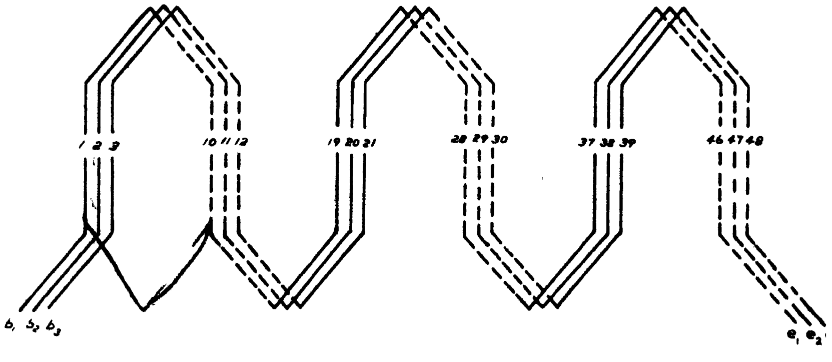


Fig. 6-4. Three coil series of phase A of a 6-pole winding with spp = 3

coil series is connected with the beginning of another coil series which lies behind the beginning of the first series, the winding is retrogressive. If, for example, in Fig. 6-4, the start of the phase lies in upper conductor 3 and the end of the series b_3-e_3 is connected with b_2, i.e., with slot 2, the winding is retrogressive.

In general, a winding is progressive, if the end of a coil series is connected with the beginning of a coil series in a slot which lies, in the direction of winding, ahead of the beginning of the coil series considered; and a winding is retrogressive if the end of a coil series is connected with the beginning of a coil series in a slot which lies, in the direction of winding, behind the beginning of the coil series considered.

The progressive winding has a certain number of front pitches which are longer than the normal-front pitch; the retrogressive winding has a certain number of front pitches which are shorter than the normal.

From the many different possible ways of starting the phases and connecting the coil series of each part and also the 2 parts of each phase, only the 2 most commonly used methods or schemes will be considered. They will be designated as the retrogressive or short-pitch (SP) connection and as the progressive-retrogressive or long pitch-short pitch (LP-SP) connection. The significance of these designations becomes clear from the following.

In this chapter, as in the foregoing chapters, the slot numbering is clockwise. The beginnings of the 2 winding parts will be designated by the odd subscripts 1 and 3, and the ends by the even subscripts 2 and 4, as for example, the beginnings of the parts of phase A will be A_1 and A_3 and the ends A_2 and A_4.

(A) WINDINGS WITH SPP = INTEGER

(a) Retrogressive (SP) connection. Fig. 6-5 shows the retrogressive (SP) connection of phase A for a 4-pole winding with spp = 3. The total number of slots is = (spp x No. of phases x No. of poles), i.e., 3 x 3 x 4 = 36. The slots belonging to phase A are 1-2-3, 10-11-12, 19-20-21, and 28-29-30 (see Fig. 6-5

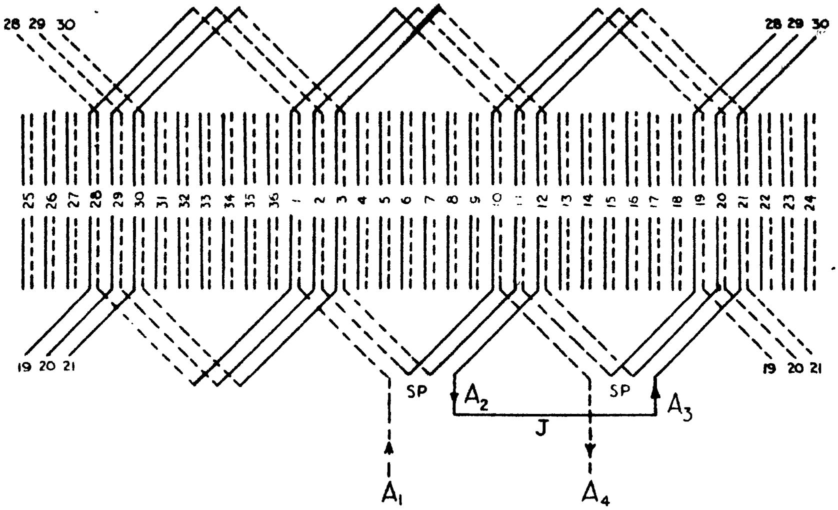


Fig. 6-5. Retrogressive or SP connection of phase A of a 4-pole winding with spp = 3

and Table 6-4). There are only 2 conductors per slot, one in each layer. The coils are left-hand (see Fig. 6-2). The back pitch and front pitch which correspond to spp = 3 are equal to 3 x 3 = 9 slot pitches (Eq. 6-1). This is the width of all coils at the end opposite the connections. For example, upper conductor 19 is connected with lower conductor 19 + 9 = 28, this latter conductor is connected with upper 28 + 9 = 37 - 36 = 1, and so on. The start A_1 of the phase lies in the lower conductor of slot 1, and the first part of the phase progresses counter-clockwise. Since spp = 3, there are 3 coil series in each winding part, each series consisting of 2 (= number of pole pairs) coils. Considering the first part, the 3 coil series are:

(1) lower 1 → upper 28 → lower 19 → upper 10.
(2) lower 2 → upper 29 → lower 20 → upper 11.
(3) lower 3 → upper 30 → lower 21 → upper 12.

The end of the first coil series (upper conductor 10) is connected with the lower conductor in slot 2. Since the first part is wound ccw (counter-clockwise), slot 2 lies in the direction of winding behind slot 1 (start of the first series) and the first part is retrogressive. This leads to shorter front pitches than normal between upper conductor 10 and lower conductor 2, and upper conductor 11 and lower conductor 3. In general, the number of shorter-front pitches per winding part is equal to (spp - 1), in this case to 3 - 1 = 2.

The end A_2 of the first part lies in the upper conductor 12, and the first part of the winding contains the lower conductors of slots 1-2-3, upper conductors of slots 28-29-30, lower conductors of slots 19-20-21, and upper conductors of slots 10-11-12. The remainder, i.e., the upper conductors of slots 1-2-3, lower conductors of slots 28-29-30, upper conductors of slots 19-20-21, and lower conductors of slots 10-11-12, make up the second part of phase A. This part starts in the upper conductor of slot 21 and is wound clockwise. The first coil series consists of the conductors upper 21 ⟶ lower 30 ⟶ upper 3 ⟶ lower 12 and the end of this series is connected with the upper conductor of slot 20, which lies in the direction of winding behind the beginning of the first coil series. Thus, the second part is also retrogressive and has 2 shorter-front pitches, exactly as the first part. The total number of shorter-front pitches per phase is equal to 2 x (spp - 1). The end of the first part A_2 is connected by a reversing jumper J with the beginning of the second part A_3, thus placing all the coils of phase A in series. A_1 and A_4 are the beginning and ending, respectively, of phase A. A_1 usually is made the lead to one of the rings or line; A_4 is usually made the star point.

(b) Progressive-retrogressive (LP-SP) connection. Fig. 6-6 shows the progressive-retrogressive or LP-SP connection for the same winding for which Fig. 6-5 shows the SP connection. Fig. 6-6 has the same number of slots, and the same slots are assigned to phase A as in Fig. 6-5. Therefore, the back, front, and winding pitches are also the same. The coils are again left-hand.

Contrary to the retrogressive (SP) connection described in (a), the first part of the progressive-retrogressive (LP-SP) connection starts in the upper conductor of slot 1 and is wound clockwise. The first coil series consists of the conductors upper 1 ⟶ lower 10 ⟶ upper 19 ⟶ lower 28. Its end (lower conductor 28) is connected with the upper conductor of slot 2 which lies, in the direction of winding, ahead of the beginning of the foregoing coil series, i.e., the first part is progressive.

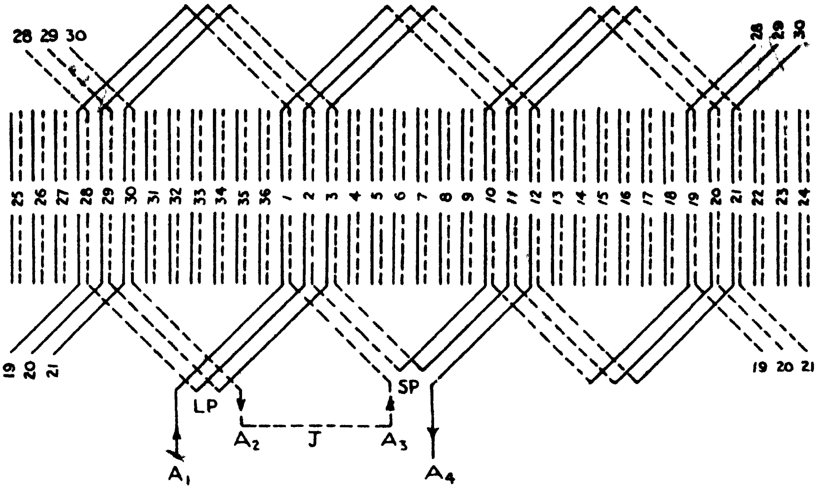


Fig. 6-6. Progressive-retrogressive or LP-SP connection of phase A of a 4-pole winding with spp = 3

This leads to longer-front pitches than normal between the lower conductor 28 and upper conductor 2, and the lower conductor 29 and upper conductor 3. The number of longer pitches is, in general, equal to (spp-1), in this case to 3 - 1 = 2. The first part ends in the lower conductor 30 and contains the upper conductors of slots 1-2-3, lower conductors of slots 10-11-12, upper conductors of slots 19-20-21, and lower conductors of slots 28-29-30. The remainder, i.e., the lower conductors of slots 1-2-3, upper conductors of slots 10-11-12, lower conductors of slots 19-20-21, and upper conductors of slots 28-29-30, make up the second part of phase A. This part starts in the lower conductor of slot 1 and is wound counter-clockwise. The first coil series consists of the conductors lower 1 → upper 28 → lower 19 → upper 10, and the end of this series (upper conductor 10) is connected to the lower conductor of slot 2 which lies, in the direction of winding, behind the beginning of the first series. Thus, the second part is retrogressive while the first part is progressive. This leads to (spp - 1) = 2 shorter-front pitches in the second part. The end of the first part A_2 is connected by a reversing jumper J with the beginning of the second part A_3, thus placing all the coils of phase A in series. A_1 and A_4 are the beginning and ending, respectively, of phase A.

Comparing the connection diagrams, Fig. 6-5 and Fig. 6-6, the SP connection has only normal- and short-front pitches while the LP-SP connection has normal-, long- and short-front pitches. The advantage of the SP connection is that it has fewer types of abnormal coils than the LP-SP connection. The advantage of the LP-SP connection is that it has no crossing of the leads and jumper.

(c) Progressive (LP) connection. Fig. 6-7 shows for comparison the same 4-pole winding with spp = 3 as in Figs. 6-5 and 6-6, but with both parts of the phase progressive. This leads to long-front pitches in both parts. The total number of long-front pitches for each phase is equal to 2 x (spp - 1). This type winding is seldom used.

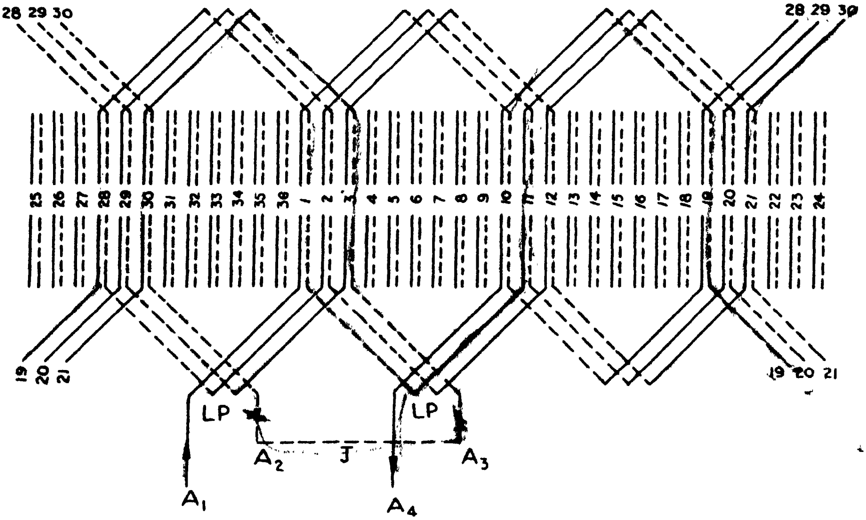


Fig. 6-7. Progressive or LP connection of phase A of a 4-pole winding with spp = 3

(d) Retrogressive (SP) connection using right-hand coils. Fig. 6-8 shows the same winding as in Fig. 6-5, i.e., with both parts retrogressive, but with right-hand coils instead of left-hand coils. Fig. 6-8 is the same as Fig. 6-5 seen from the reverse side of the page. Here also, only normal- and short-front pitches are present.

As mentioned above, the Tables and Working Diagrams given in the following are based on the retrogressive or SP connection

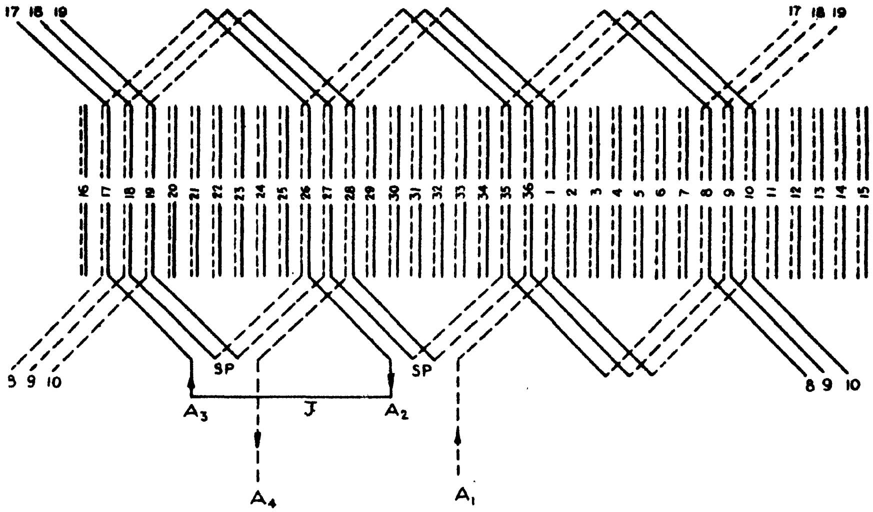


Fig. 6-8. Retrogressive connection of phase A of a 4-pole winding using right-hand coils

and the progressive-retrogressive or LP-SP connection shown in Fig. 6-5 and 6-6, respectively. Further, left-hand coils and clockwise numbering of the slots will be assumed. Upon this basis, the following applies to windings having spp = integer.

Retrogressive or SP Connection	Progressive-retrogressive or LP-SP Connection
Start of phase A lies in the lower conductor of slot 1.	The start of phase A lies in the upper conductor of slot 1.
The first part of the phase is retrogressive and progresses ccw.	The first part of the phase is progressive and progresses cw.
The second part of the phase is retrogressive and progresses cw.	The second part of the phase is retrogressive and progresses ccw.
The jumper from part 1 to part 2 progresses cw and connects 2 upper conductors.	The jumper from part 1 to part 2 progresses cw and connects 2 lower conductors.
The beginning and ending of a phase lie in lower conductors.	The beginning and ending of a phase lie in upper conductors.
See Fig. 6-5.	**See Fig. 6-6.**

(B) WINDINGS WITH SPP = (INTEGER + 1/2)

(a) Retrogressive (SP) connection. As an example, a 4-pole winding with spp = 3 1/2 (Fig. 6-9) will be considered. The total number of slots is equal to (spp x No. of phases x No. of poles) = 3 1/2 x 3 x 4 = 42, and there are 42 upper and 42 lower conductors. Since spp is a fractional number, namely 3 1/2, one part of each phase will have 4 coil series and the other part 3 coil series. The back pitch (see Eq. 6-1) is (3 x spp) + 1/2 = (3 x 3 1/2) + 1/2 = 11, and the front pitch is (back pitch - 1) = (11 - 1) = 10.

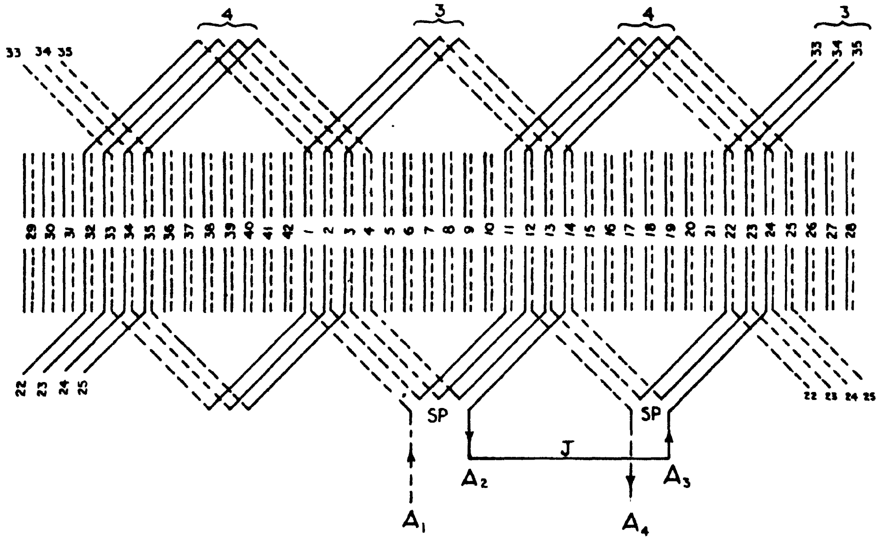


Fig. 6-9. Retrogressive or SP connection of phase A of a 4-pole winding with spp = 3 1/2

Assigning the upper (or lower) conductors to the 3 phases, conductor groups of (spp + 1/2) = 4 and (spp - 1/2) = 3 conductors must alternate. For the example considered, the lower conductors may be distributed as follows:

Lower Conductors	1-2-3-4	5-6-7	8-9-10-11	12-13-14
Phase	A	C	B	A
Lower Conductors	15-16-17-18	19-20-21	22-23-24-25	26-27-28
Phase	C	B	A	C
Lower Conductors	29-30-31-32	33-34-35	36-37-38-39	40-41-42
Phase	B	A	C	B

i.e., to phase A belong the lower conductor groups

1-2-3-4   12-13-14   22-23-24-25   33-34-35

When the distribution of the lower conductors is fixed, the distribution of the upper conductors is also fixed, since at the end opposite the connection-end the distance between a lower and upper conductor is fixed by the back pitch, which is equal here to 11 slot pitches. Thus, with left-hand coils, the lower conductor 1 is connected to the upper conductor (1 + 42) - 11 = 32. The lower conductor 2 is connected with the upper conductor (2 + 42) - 11 = 33, and so on, and the upper conductors belonging to phase A are

1-2-3   11-12-13-14   22-23-24   32-33-34-35

Fig. 6-9 shows, for phase A, the retrogressive or SP connection of the considered 4-pole winding with spp = 3 1/2. This connection corresponds to the connection of Fig. 6-5, except that here both parts of the phase do not have the same number of coil series. The first part, progressing counter-clockwise, has (spp + 1/2) = 3 1/2 + 1/2 = 4 coil series, while the second part, progressing clockwise has (spp - 1/2) = 3 1/2 - 1/2 = 3 coil series.

The first part starts, as in Fig. 6-5, in the lower conductor of slot 1 and its first coil series goes through 2 (= number of pole pairs) coils, i.e., through the conductors

lower 1 → upper 32 → lower 22 → upper 11

The latter conductor is connected to the lower conductor 2 which, in the direction of winding, is behind the beginning of the first coil series. The winding is, therefore, retrogressive, and 3 shorter-front pitches will appear in this part of the phase. The second part starts in the upper conductor of slot 24 and consists of 3 coil series. It is also retrogressive and produces 2 shorter-front pitches.

The number of shorter-front pitches is, in general, equal to the number of coil series minus 1, i.e., in one part equal to (spp + 1/2) - 1 or spp - 1/2, and in the other part to (spp - 1/2) - 1 or (spp - 1 1/2).

As in Fig. 6-5, both parts of the phase are connected by a reversing jumper J which places all coils of the phase in series.

(b) Progressive-retrogressive (LP-SP) connection. Fig. 6-10 shows the progressive-retrogressive or LP-SP connection for the

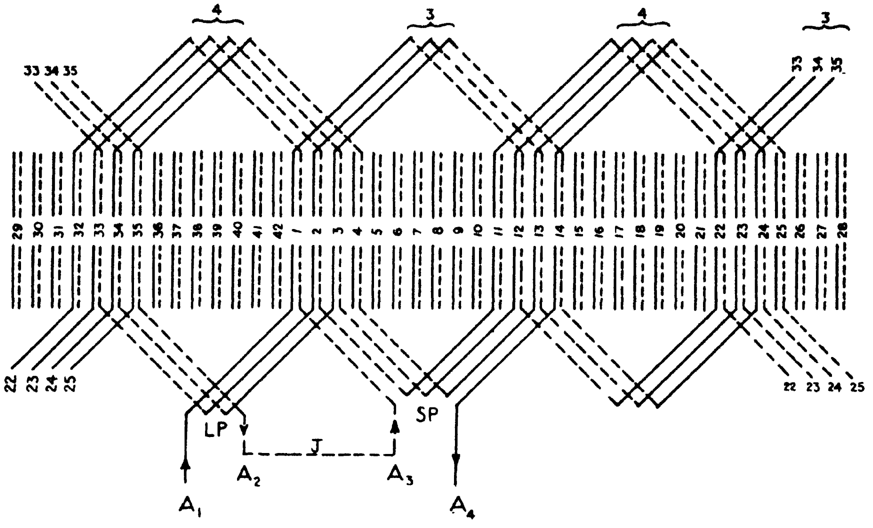


Fig. 6-10. Progressive-retrogressive or LP-SP connection of phase A of a 4-pole winding with spp = 3 1/2

4-pole winding with spp = 3 1/2 considered above. This connection corresponds to the connection of Fig. 6-6, except that here both parts of the phase do not have the same number of coil series. The distribution of the conductors among the phases is the same as in Fig. 6-9. As in Fig. 6-6, the first part of the phase is progressive and the second retrogressive. Contrary to Fig. 6-9, the first part has (spp - 1/2) = 3 1/2 - 1/2 = 3 coil series, and the second part has (spp + 1/2) = 3 1/2 + 1/2 = 4 coil series. Therefore, the first progressive part produces 2 (= number of coil series minus 1) longer-front pitches, and the second retrogressive part produces 3 (= 4 - 1) shorter-front pitches. Both parts of the phase are connected in series by the reversing jumper J.

Summarizing, the following applies to windings for spp = (integer + 1/2):

Retrogressive or SP Connection	Progressive-retrogressive or LP-SP Connection
The start of phase A lies in the lower conductor of slot 1.	The start of phase A lies in the upper conductor of slot 1.
The first part of the phase is retrogressive, progresses ccw, and consists of (spp + 1/2) coil series.	The first part of the phase is progressive, progresses cw, and consists of (spp - 1/2) coil series.
The second part of the phase is retrogressive, progresses cw, and consists of (spp - 1/2) coil series.	The second part of the phase is retrogressive, progresses ccw, and consists of (spp + 1/2) coil series.
The jumper from part 1 to part 2 progresses cw, and connects 2 upper conductors.	The jumper from part 1 to part 2 progresses cw, and connects 2 lower conductors.
The beginning and end of a phase lie in lower conductors.	The beginning and end of a phase lie in upper conductors.
(See Fig. 6-9)	(See Fig. 6-10)

6-3. Connection Tables, Conductor Distribution Tables, Working Diagrams, and How to Use Them. The information necessary to produce a winding for a given spp and number of poles is as follows:

1. Back pitch
2. Front pitch
3. Exact position of the leads
4. The position of the reversing jumper ends.
5. The beginning and ending of a coil series.
6. Number of shorter- and longer-front coil pitches.
7. Number of normal-front coil pitches.
8. The sequence of the various parts.

The Connection Table gives all the information necessary to produce a winding. Twenty-four Connection Tables (6-1 to 6-24) are given; 12 for the retrogressive (SP) connection and 12 for the progressive-retrogressive (LP-SP) connection. In both cases, the Tables are worked out for

spp = 1 1/2, 2, 2 1/2, 3	for 4 to 24 poles
spp = 3 1/2	for 4 to 18 poles
spp = 4	for 4 to 14 poles
spp = 4 1/2	for 4 to 12 poles
spp = 5, 5 1/2	for 4 to 10 poles
spp = 6, 7, 8	for 4 to 8 poles

It should be noted that 4-pole rotor windings are often made lap instead of wave.

Conductor-distribution Tables 6-25 to 6-41 are given to show the distribution of the conductors among the 3 phases and to be used for checking the Connection Tables and arranging the winding in parallel circuits (see Arts. 6-9 and 6-10). The Conductor-Distribution Tables also enable the winder to change the spacing between the beginnings of the phases, if necessary (see Art. 6-4).

The Working Diagrams are skeleton diagrams but show all the necessary connections for a given spp and for a given number of poles.

For the retrogressive (SP) connection, the following Working Diagrams are given:

Poles	6	8	10	12	14	16	18	20	22	24
spp	Fig. No.									
2	6-17	6-25	6-32	6-38	6-43	6-48	6-52	6-56	6-59	6-62
2½	6-18	6-26	6-33	6-39	6-44	6-49	6-53	6-57	6-60	6-63
3	6-19	6-27	6-34	6-40	6-45	6-50	6-54	6-58	6-61	6-64
3½	6-20	6-28	6-35	6-41	6-46	6-51	6-55			
4	6-21	6-29	6-36	6-42	6-47					
4½	6-22	6-30	6-37							
5	6-23	6-31								
6	6-24									

For the progressive-retrogressive (LP-SP) connection, the following Working Diagrams are given:

Poles	6	8	10	12	14	16	18	20	22	24
spp	Fig. No.									
2	6-65	6-73	6-80	6-86	6-91	6-96	6-100	6-104	6-107	6-110
2½	6-66	6-74	6-81	6-87	6-92	6-97	6-101	6-105	6-108	6-111
3	6-67	6-75	6-82	6-88	6-93	6-98	6-102	6-106	6-109	6-112
3½	6-68	6-76	6-83	6-89	6-94	6-99	6-103			
4	6-69	6-77	6-84	6-90	6-95					
4½	6-70	6-78	6-85							
5	6-71	6-79								
6	6-72									

The above working diagrams are shown at the end of the chapter. The development of a Working Diagram will be shown and explained by an example.

Fig. 6-11 shows a completely developed retrogressive (SP) wave winding for 72 slots, 8 poles, spp = 3, and 2 conductors per slot. The short radial lines numbered 1 to 72 indicate the slot portion of the winding. The outer circle represents the portion of the winding opposite the lead-end, while the inner circle represents the lead-end and shows the position of the starts and ends of the winding, the jumper connections, and the number of coil connections between the starts, ends, and jumper leads.

The number of connections between upper and lower conductors at the end opposite the lead-end is equal to the number of coils, i.e., 72 in this example. However, the number of connections between upper and lower conductors at the lead-end is less than the number of coils because there are 4 free ends to each phase (A_1, A_2, A_3, A_4, B_1, B_2, etc.). The total number of connections between upper and lower conductors at the lead-end is equal to the number of coils less 6.

Since spp = 3, the back pitch as well as the front pitch = 9 slot pitches. Thus, lower conductor 1 is connected with

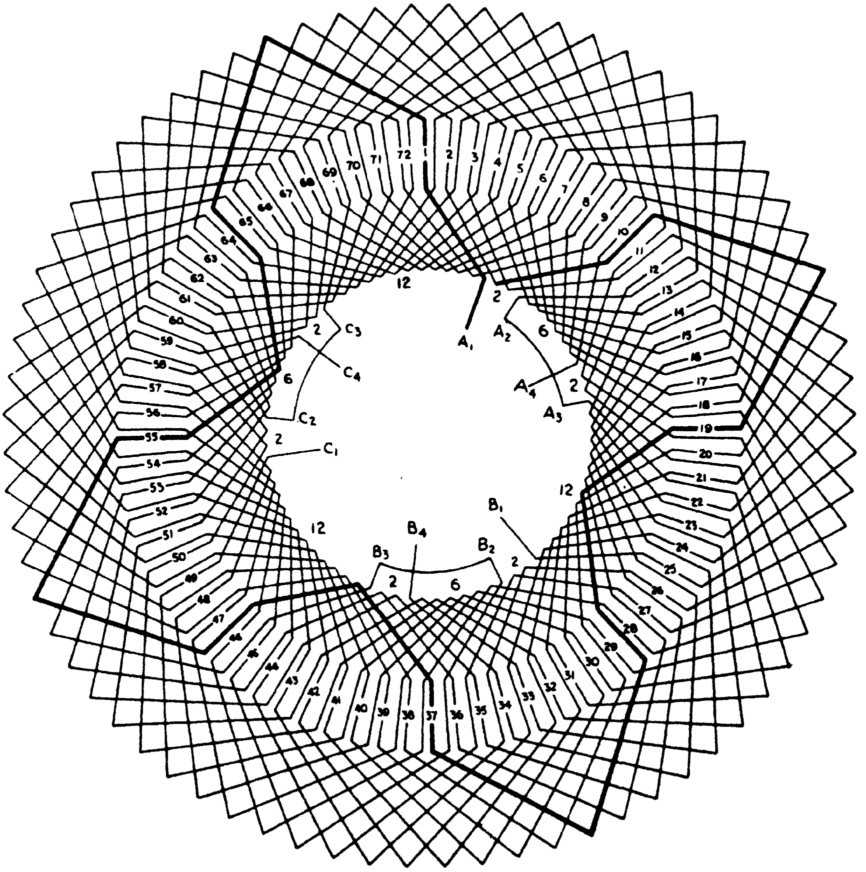


Fig. 6-11. Fully developed winding with retrogressive (SP) connection for 72 slots, 8 poles, and spp = 3.

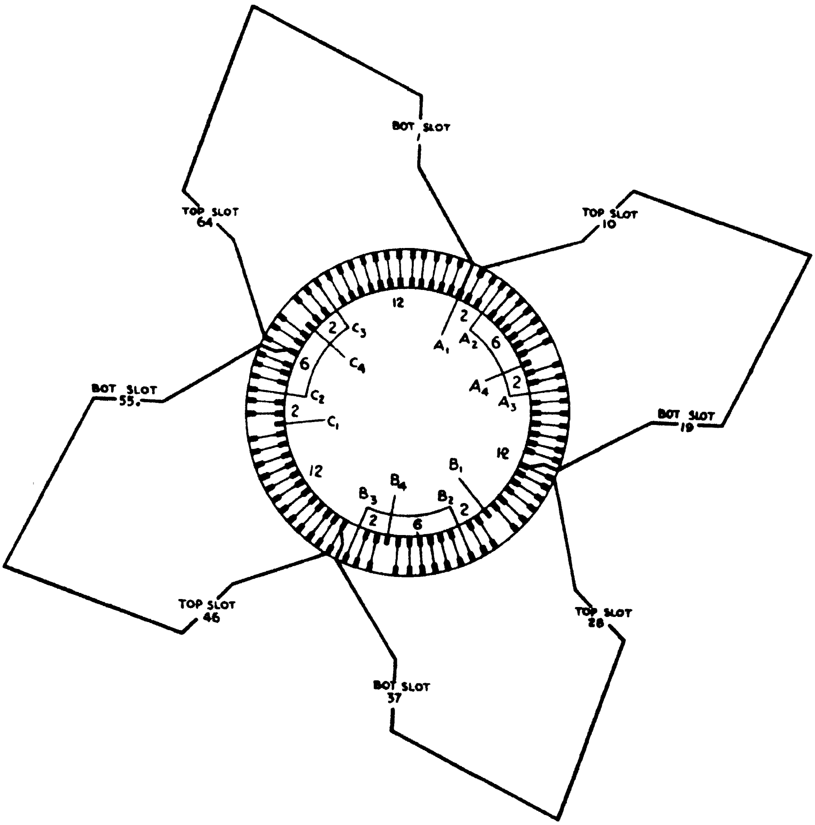


Fig. 6-12. Simplified diagram of the retrogressive (SP) connection of the winding shown in Fig. 6-11

upper conductor 64 then with lower conductor 55, etc., until the end of the first coil series ends in upper 10 and connects with the beginning of the next coil series in lower 2. This first coil series is shown by a heavy line in Fig. 6-11.

Fig. 6-12 is a simplified form of Fig. 6-11. The single coil series, shown by a heavy line in Fig. 6-11, is again shown in the same relative position in Fig. 6-12. All the other coil series are omitted, but the connections between top and bottom conductors at the lead-end are shown by short radial lines between 2 concentric circles. This part of the diagram, which corresponds to the internal circle of Fig. 6-11, shows the position of the leads and jumpers, and designates the number of connections between the upper and lower conductors. The outer circle of squares (Fig. 6-12) designates the top conductors; the inner circle, the bottom conductors. The short radial lines connecting these points represent clips or connections between top and bottom conductors. For example, between A_1 and A_2 there are 2 clips or connections joining 2 upper and 2 lower conductors.

The further simplification of Fig. 6-12 is shown in Fig. 6-13. Here only the beginning and end of the same coil series of phase A are shown. The radial lines representing clips are shown only in the region of the leads of phase A; in all other parts of the diagram, a number is shown which denotes the number of coils or clips between the parts. This diagram is the same as the Working Diagram of Fig. 6-27. This skeleton diagram then suffices to install the winding.

If half-turn coils are used, the winder installs all the bottom conductors, marking the lower conductor of slot 1. Next he installs all the top conductors. Starting with lower conductor 1 and connecting it with upper conductor 64, all the connections between upper and lower conductors are then made in sequence, at the end opposite the lead-end. At the lead-end, lower conductor 1 is marked for connection to the rings. Upper conductor 10 is connected by a clip with lower conductor 2, and upper conductor 11 to lower conductor 3. This agrees with the diagram which shows 2 connections between upper and lower conductors progressing clockwise from A_1.

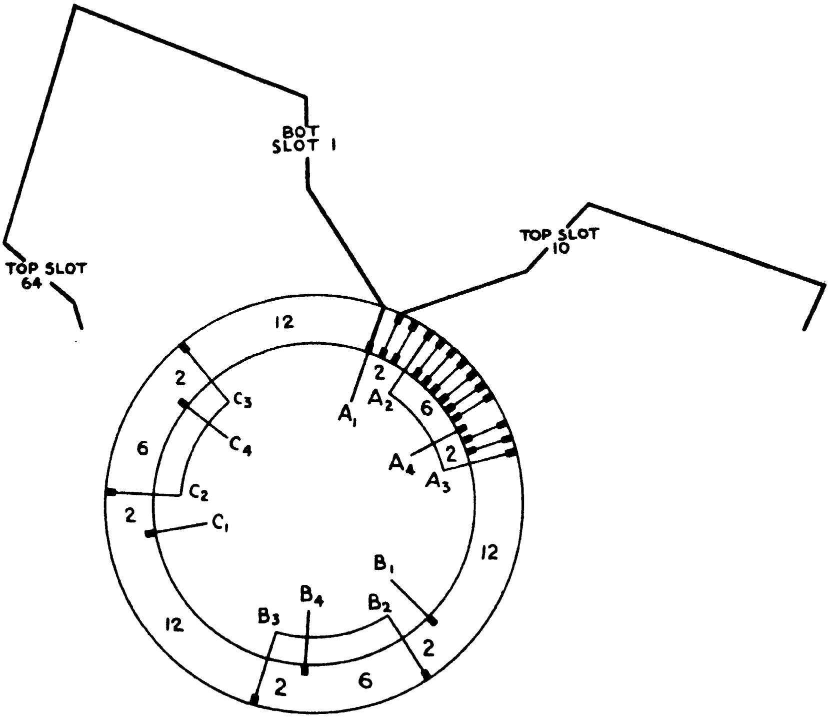


Fig. 6-13. Working diagram of the retrogressive (SP) connection of the winding shown in Fig. 6-11

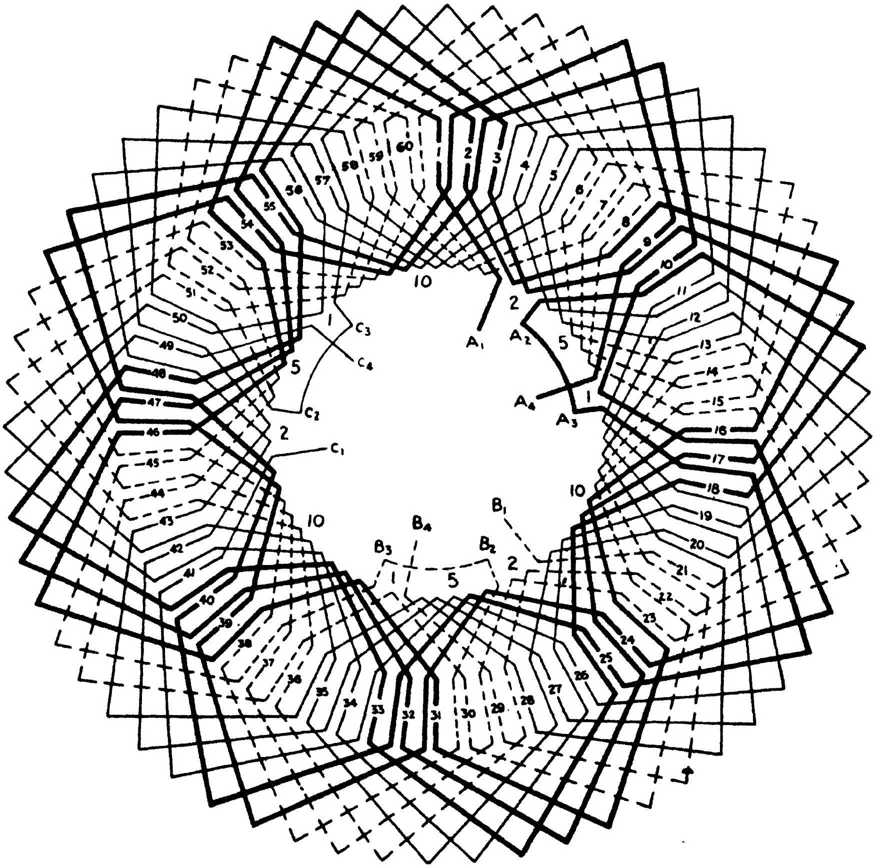


Fig. 6-14. Fully developed winding with a retrogressive (SP) connection for 60 slots, 8 poles, and spp = 2 1/2

The next upper conductor is a jumper lead A_2. There follow then 6 clips or connections joining 6 upper and 6 lower conductors. The next lower conductor is a lead A_4, which is then followed by 2 connections between 2 upper and 2 lower conductors. The next upper conductor is a jumper A_3 which connects with A_2. There follow 12 connections between 12 upper and 12 lower conductors. The process continues on around until the winding is completely connected.

If full-turn coils are used, the winder installs and marks the first coil as the number one coil. The bottom coil side is placed in the bottom of slot 1 and the top coil side in slot 64 (because the back pitch = 9 slot pitches in this case). Progressing clockwise facing the connection end, the winder installs the coils in the normal manner, until a bottom coil side is placed in the bottom of slot 19 and the corresponding top coil side in slot 10. This latter coil side (conductor) is now marked for connection with the bottom conductor of slot 2. This now fixes the beginning reference points. The remaining coils are now installed, and the winder will refer back to the starting position and make the connections of the coil ends according to the sequence given by the corresponding working diagram. A method of checking the connections is given in Chapter 12, Art. 12-3.

Fig. 6-14 represents a fully developed 8-pole winding in 60 slots with retrogressive (SP) connection; spp = 2 1/2. The final Working Diagram is Fig. 6-26.

Fig. 6-15 shows a fully developed 8-pole winding in 72 slots with progressive-retrogressive (LP-SP) connection; spp = 3. The final Working Diagram is Fig. 6-75.

Fig. 6-16 shows a fully developed 8 pole winding in 60 slots with progressive-retrogressive (LP-SP) connection; spp = 2 1/2. The final Working Diagram is Fig. 6-74.

The use of the Tables and Working Diagrams will be explained by several examples:

Example 1

A 10-pole rotor has 90 slots and is to be wound with a retrogressive winding. The Master Table 3-5 yields for 90 slots and 10 poles an spp = 3. The Connection Table 6-4 for retro-

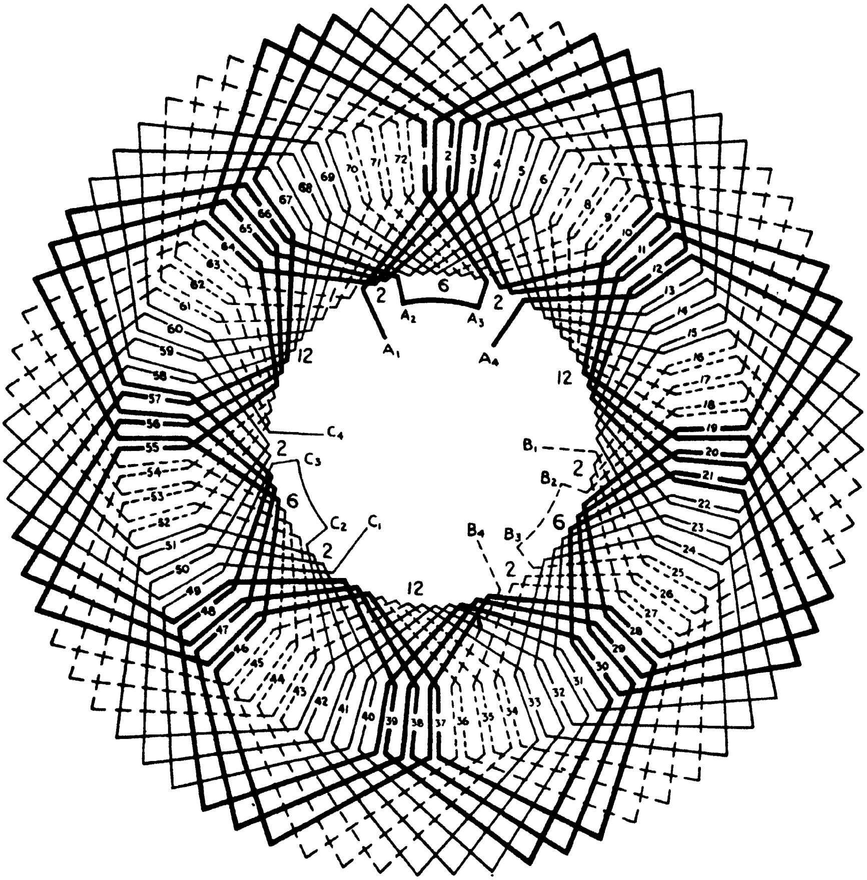


Fig. 6-15. Fully developed winding with a progressive-retrogressive (LP-SP) connection for 72 slots, 8 poles, and spp = 3

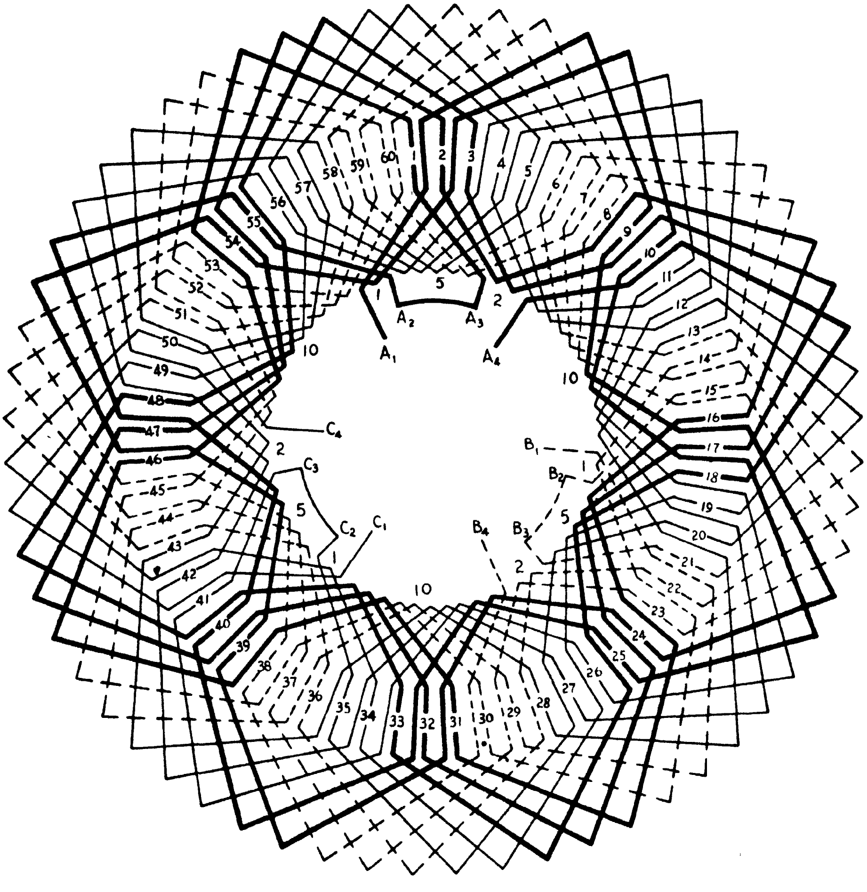


Fig. 6-16. Fully developed winding with a progressive-retrogressive (LP-SP) connection for 60 slots, 8 poles, and spp = 2 1/2

gressive (SP) connection, and spp = 3, gives the following position of the leads and reversing jumpers for 10 poles:

Leads	Reversing Jumpers
A_1 = in bottom conductor 1	A_2 = in top conductor 12
A_4 = in bottom conductor 10	A_3 = in top conductor 21
B_1 = in bottom conductor 61	B_2 = in top conductor 72
B_4 = in bottom conductor 70	B_3 = in top conductor 81
C_1 = in bottom conductor 31	C_2 = in top conductor 42
C_4 = in bottom conductor 40	C_3 = in top conductor 51

The Conductor-distribution Table 6-30 shows the assignment of the slots to the various phases, and confirms that slots 1, 10, 12, 21 belong to phase A; slots 61, 70, 72, 81 belong to phase B; and slots 31, 40, 42, 51 belong to phase C.

The Connection Table 6-4 indicates that the back pitch = the front pitch = 9 slot pitches. Further the Connection Table gives the number and location of the shorter and normal front pitch coils. This, together with the Distribution Table, serves to give the necessary information to lay out the completely developed winding or to prepare the Working Diagram. The Working Diagram of this winding is given in Fig. 6-34. The short radial lines represent clips. There are shown on this figure the beginning and end of the first coil series of phase A, the back pitch, and the sequence of the shorter and normal front pitches, i.e., coils, for all 3 phases. Since spp = 3, the back as well as the front pitch is equal to 3 x 3 = 9 slot pitches. Thus, lower conductor 1 is connected with upper conductor (1 + 90) - 9 = 82, and the last conductor of the first coil series of phase A is the top conductor (1 + back pitch) = 1 + 9 = 10. (See Fig. 6-113.) The start of each phase is followed by (spp - 1) = 3 - 1 = 2 short-front pitch coils, then by the jumper and 2 x spp = 2 x 3 = 6 normal-front-pitch coils, then by the second lead and again by (spp - 1) = 2 short-front-pitch coils, then again by the jumper and finally by 18 normal-front-pitch coils. The beginning and end of each phase are connected to lower conductors, the jumpers to upper conductors. The Connection Table gives the same information.

Example 2

A 14-pole rotor has 147 slots and is to be wound with a retrogressive winding. The Master Table 3-5 yields for 147 slots and 14 poles an spp = 3 1/2. The Connection Table 6-5 for retrogressive (SP) connection and spp = 3 1/2 gives the following position of leads and reversing jumpers for 14 poles:

Leads	Jumpers
A_1 = in bottom conductor 1	A_2 = in top conductor 14
A_4 = in bottom conductor 12	A_3 = in top conductor 24
B_1 = in bottom conductor 50	B_2 = in top conductor 63
B_4 = in bottom conductor 61	B_3 = in top conductor 73
C_1 = in bottom conductor 99	C_2 = in top conductor 112
C_4 = in bottom conductor 110	C_3 = in top conductor 122

The Conductor-distribution Tables 6-31 and 6-32 show the assignment of the slots to the various phases and confirm that slots 1, 12, 14, 24 belong to phase A; slots 50, 61, 63, 73 belong to phase B; and slots 99, 110, 112, 122 belong to phase C. The Conductor-distribution Tables can also be used for changing the spacing between the beginnings of the phases if necessary (see Art. 6-4). The Connection Table 6-5 shows that the back pitch is equal to 11 slot pitches and the front pitch is equal to 10 slot pitches. Further, the Connection Table gives the number and location of the short- and normal-front pitches.

The Working Diagram of the winding is given in Fig. 6-46. The back pitch is (3 x spp) + 1/2 = 3 x 3 1/2 + 1/2 = 11, and the front pitch is (back pitch - 1) = 11 - 1 = 10. Therefore, the lower conductor 1 is connected with the upper conductor (1 + 147) - 11 = 137, and the last conductor of the first coil series of phase A is the top conductor 11 (= back pitch). (See Fig. 6-114.) The start of each phase is followed by (spp - 1/2) = 3 1/2 - 1/2 = 3 short-front-pitch coils, then by the jumper and 2 x spp = 2 x 3 1/2 = 7 normal-front-pitch coils, then by the second lead and (spp - 1 1/2) = 3 1/2 - 1 1/2 = 2 short-front-pitch coils, then again by the jumper and finally by 35 normal-front-pitch coils. The beginning and end of each phase are connected to lower conductors, the jumpers to upper conductors. The Connection Table gives the same information.

Example 3

A 6-pole rotor has 54 slots and is to be wound with a progressive-retrogressive winding. The Master Table 3-5 yields for 54 slots and 6 poles an spp = 3. The Connection Table 6-16 for progressive-retrogressive (LP-SP) connection and spp = 3 gives the following position of leads and jumpers for 6 poles:

Leads	Jumpers
A_1 = in top conductor 1	A_2 = in bottom conductor 48
A_4 = in top conductor 12	A_3 = in bottom conductor 1
B_1 = in top conductor 25	B_2 = in bottom conductor 18
B_4 = in top conductor 36	B_3 = in bottom conductor 25
C_1 = in top conductor 13	C_2 = in bottom conductor 6
C_4 = in top conductor 24	C_3 = in bottom conductor 13

The Connection Table shows that the back pitch = front pitch = 9 slot pitches. Further, the Connection Table shows that the first or clockwise going part of each phase has 2 long-front pitches, while the second or counter-clockwise going part of each phase has 2 short-front pitches. The Table also shows that there are 6 normal-front pitches between A_2 and A_3, B_2 and B_3, and C_2 and C_3.

The conductor distribution of this winding is given in Table 6-30 and the Working Diagram is given in Fig. 6-67. The back and front pitches are equal to (3 x spp) = 3 x 3 = 9 slot pitches. Therefore, upper conductor 1 is connected with lower conductor 1 + 9 = 10 and the last conductor of the first coil series of phase A is the bottom conductor (1 + number of slots - back pitch) = 1 + 54 - 9 = 46. (See Fig. 6-115). The start of each phase is followed by (spp - 1) = 3 - 1 = 2 long-front-pitch coils, then by the jumper and (2 x spp) = 2 x 3 = 6 normal-front-pitch coils, then again by the jumper and (spp - 1) = 3 - 1 = 2 short-front-pitch coils, and then by the end of each phase. Between lead A_4 and lead C_1, and also between lead C_4 and lead B_1, there are no coils, but between lead B_4 and lead A_1 there are 18 normal-front-pitch coils.

In the foregoing examples of a 10-pole and a 14-pole winding, the beginnings of the 3 phases are 120 mechanical, as well as electrical, degrees apart, and the number of normal-front-pitch coils between the second jumper lead and the beginning of the next following phase is the same for all 3 phases. The equal spacing of the 3 phase beginnings is not possible when the number of poles is 6 or a multiple of 6, i.e., 12, 18, 24, and so on. In these cases, the number of normal-front-pitch coils between the leads (or second jumper lead) is determined by the Connection Table.

Consider again the Connection Table 6-16 of the 6-pole winding. The second lead or end of phase A lies in the top of slot 12, and the beginning of phase C lies in the top of slot 13. Further, the second lead of phase C lies in the top of slot 24, and the beginning of phase B lies in the top of slot 25. Therefore, there are no normal-front-pitch coils between the end of phase A (A_4) and the beginning of phase C (C_1) as well as between the end of phase C (C_4) and the beginning of phase B (B_1), but there are 18 normal-front-pitch coils between the ends of phase B (B_4) and the beginning of phase A (A_1).

6-4. General Rules for Laying Out Conductor-distribution Tables and Connection Tables. In order to lay out a Connection Table, first the starts of the 3 phases, A_1, B_1, and C_1 (see Figs. 6-5, 6-6, 6-9, and 6-10), must be determined. For this purpose, either a Conductor-distribution Table can be used, if available, or the formulae given below.

A wave winding with spp = integer is laid out in the same way as the integral-slot lap winding. For example, for spp = 3, the assignment of the slots to the 3 phases is as follows:

1-2-3	4-5-6	7-8-9	10-11-12	13-14-15	16-17-18
A	C	B	A	C	B

When spp = (integer + 1/2), (spp + 1/2) and (spp - 1/2) slots, alternating, are to be assigned to the 3 phases. This applies to the retrogressive (SP) connection, as well as to the progressive-retrogressive (LP-SP) connection considered in the foregoing. For example, for spp = 3 1/2, the assignment of the lower conductors to the 3 phases is as follows:

1-2-3-4	5-6-7	8-9-10-11	12-13-14	15-16-17-18	19-20-21
A	C	B	A	C	B

For the upper conductors the distribution is then (see Art. 6-2)

1-2-3	4-5-6-7	8-9-10	11-12-13-14	15-16-17	18-19-20-21
A	C	B	A	C	B

The formulae which can be used instead of the Conductor-distribution Table are:

$$\left.\begin{array}{l} A_1 \text{ lies in slot } 1 \\ B_1 \text{ lies in slot } (1 + 2 \times \text{spp}) + \dfrac{2 \times \text{No. of slots}}{\text{No. of poles}} \times \text{Integer} \\ C_1 \text{ lies in slot } (1 + 4 \times \text{spp}) + \dfrac{2 \times \text{No. of slots}}{\text{No. of poles}} \times \text{Integer} \end{array}\right\} \text{(6-2)}$$

The integer can be 0, 1, 2, 3, and so on. Its value is usually different for B_1 and C_1. The integers determine the spacing of the phase beginnings around the rotor and are chosen in such a manner that the distance between the 3 phase beginnings is 120 mechanical degrees. As explained in Art. 6-3, this is possible only for the pole numbers which are not equal to 6 or a multiple of 6. The formulae apply to spp = integer as well as to spp = (integer + 1/2).

Once the phase beginnings are fixed, the second lead A_4, and the leads to the reversing jumper A_2 and A_3, can be determined from the following formulae:

(a) Retrogressive (SP) connection, spp = integer

$$\begin{aligned} A_2 &= A_1 + (\text{back pitch} + \text{spp}-1) \\ B_2 &= B_1 + (\text{back pitch} + \text{spp}-1) \\ C_2 &= C_1 + (\text{back pitch} + \text{spp}-1) \\ A_3 &= A_2 + \text{back pitch} \\ B_3 &= B_2 + \text{back pitch} \\ C_3 &= C_2 + \text{back pitch} \\ A_4 &= A_1 + \text{back pitch} \\ B_4 &= B_1 + \text{back pitch} \\ C_4 &= C_1 + \text{back pitch} \end{aligned} \qquad \text{(6-3a)}$$

$$\left.\begin{array}{l} \text{Number of short-front-pitch coils between } A_1 \\ \quad \text{and } A_2, = \text{spp} - 1 \\ \text{Number of short-front-pitch coils between } A_4 \\ \quad \text{and } A_3, = \text{spp} - 1 \end{array}\right\} \text{(See Fig. 113)}$$

(b) Retrogressive (SP) connection, spp = (integer + 1/2)

$$\begin{aligned} A_2 &= A_1 + (\text{back pitch} + \text{spp}-1\ 1/2) \\ A_3 &= A_2 + (\text{back pitch} -1) \\ A_4 &= A_1 + \text{back pitch} \\ B_2 &= B_1 + (\text{back pitch} + \text{spp}-1\ 1/2) \\ B_3 &= B_2 + (\text{back pitch} -1) \\ B_4 &= B_1 + \text{back pitch} \end{aligned} \qquad \text{(6-3b)}$$

$$\begin{aligned}
C_2 &= C_1 + (\text{back pitch} + \text{spp-1 } 1/2)\\
C_3 &= C_2 + (\text{back pitch } -1)\\
C_4 &= C_1 + \text{back pitch}
\end{aligned}$$

$$\left.\begin{array}{l}
\text{Number of short-front-pitch coils between } A_1\\
\quad \text{and } A_2 = \text{spp} - 1/2\\
\text{Number of short-front-pitch coils between } A_4\\
\quad \text{and } A_3 = \text{spp} - 1\ 1/2
\end{array}\right\} \text{(See Fig. 114)}$$

(c) Progressive-retrogressive (LP-SP) connection, spp = integer

$$\begin{aligned}
A_2 &= A_1 + (\text{number of slots} - \text{back pitch} + \text{spp-1})\\
A_3 &= A_1\\
A_4 &= A_1 + (\text{back pitch} + \text{spp-1})\\
B_2 &= B_1 + (\text{number of slots} - \text{back pitch} + \text{spp-1})\\
B_3 &= B_1\\
B_4 &= B_1 + (\text{back pitch} + \text{spp-1})\\
C_2 &= C_1 + (\text{number of slots} - \text{back pitch} + \text{spp-1})\\
C_3 &= C_1\\
C_4 &= C_1 + (\text{back pitch} + \text{spp-1})
\end{aligned}\tag{6-3c}$$

$$\left.\begin{array}{l}
\text{Number of long-front-pitch coils between } A_1\\
\quad \text{and } A_2 = \text{spp-1}\\
\text{Number of short-front-pitch coils between } A_3\\
\quad \text{and } A_4 = \text{spp-1}
\end{array}\right\} \text{(See Fig. 115)}$$

(d) Progressive-retrogressive (LP-SP) connection, spp = (integer + 1/2)

$$\begin{aligned}
A_2 &= A_1 + (\text{number of slots} - \text{back pitch} + \text{spp-1/2})\\
A_3 &= A_1\\
A_4 &= A_1 + (\text{back pitch} + \text{spp-1 } 1/2)\\
B_2 &= B_1 + (\text{number of slots} - \text{back pitch} + \text{spp-1/2})\\
B_3 &= B_1\\
B_4 &= B_1 + (\text{back pitch} + \text{spp-1 } 1/2)\\
C_2 &= C_1 + (\text{number of slots} - \text{back pitch} + \text{spp-1/2})\\
C_3 &= C_1\\
C_4 &= C_1 + (\text{back pitch} + \text{spp-1 } 1/2)
\end{aligned}\tag{6-3d}$$

$$\left.\begin{array}{l}
\text{Number of long-front-pitch coils between } A_1\\
\quad \text{and } A_2 = \text{spp-1 } 1/2\\
\text{Number of short-front-pitch coils between } A_3\\
\quad \text{and } A_4 = \text{spp-1/2}
\end{array}\right\} \text{(See Fig. 116)}$$

For the retrogressive (SP) connection, 2 X spp normal-front-pitch coils always lie between A_2 and A_4, and for the progressive-retrogressive (LP-SP) connection 2 x spp normal-front-pitch coils always lie between A_2 and A_3. This fact can also be used in order to check or determine the spp of a wave winding.

When the number of conductors per slot is larger than 2 (see Art. 6-6), then the number of clips counted between A_2 and A_4 or A_2 and A_3 must be divided by the number of conductors per layer, in order to determine the real spp.

The number of normal-front-pitch coils which follow the reversing jumper lead A_3, in retrogressive (SP) windings (Figs. 6-113 and 6-114), or the lead A_4, in progressive-retrogressive (LP-SP) windings (Figs. 6-115 and 6-116), depends upon the total number of slots and the number of poles. It has been pointed out in Art. 6-3 that equal spacing between the phase beginnings can be achieved only in the windings with the number of poles different from 6 or a multiple of 6. In the cases of equal spacing, the number of normal-front-pitch coils between the jumper lead A_3, in retrogressive (SP) windings, or lead A_4, in progressive-retrogressive (LP-SP) windings, and the beginning of the next phase is equal to

$$\frac{\text{No. of slots}}{3} - 4 \times \text{spp}$$

When the number of poles is equal to 6 or a multiple of 6, the number of normal-front-pitch coils between A_3, in retrogressive windings, or A_4, in progressive-retrogressive windings, and the beginning of the next phase depends upon the slot in which the next phase starts. The latter is to be taken from a Connection Table, if available, or is to be determined for each case.

The same 3 examples will be considered as in Art. 6-3.

Example 1

10-pole rotor with 90 slots and retrogressive (SP) connection. Here, spp = 3, back pitch = front pitch = 9 slot pitches (See Eq. 6-1). The beginning of phase A lies in slot 1. The beginning of phase B can lie in slot $(1 + 2 \times 3) + \frac{2 \times 90}{10} \times$ integer = 7 + 18 x integer (See Eq. 6-2). The integer can be equal to 0, 1, 2, or 3, i.e., the beginning of phase B can lie in one of the slots 7, 25, 43, 61, or 79. The beginning of phase C can lie in slot (1 + 4 x 3) + 18 x integer = 13 + 18 x integer where the integer 0, 1, 2, or 3, i.e., the beginning of phase C can lie in one of the slots 13, 31, 49, 67, or 85.

Equal spacing between the phase beginnings is achieved when phase A starts in slot 1 and the other 2 phases start in slots $(1 + \frac{90}{3})$ and $(1 + 2 \times \frac{90}{3})$, respectively, i.e., in the slots 31 and 61. Therefore, the start of phase C will be put in slot 31 and the start of phase B in slot 61. The same result is obtained from the Conductor-distribution Table 6-30 for spp = 3. Note that the slot chosen for the beginning of phase B must have the same polarity as slot 7, and the slot chosen for the beginning of phase C must have the same polarity as slot 13, i.e., the slot chosen for the beginning of a phase must have the same polarity as the first slot of the series of slots possible as beginnings for this phase.

For the other leads of the 3 phases, the formula (6-3a) yields:

$$A_2 = 1 + (9 + 3 - 1) = 12$$
$$B_2 = 61 + (9 + 3 - 1) = 72$$
$$C_2 = 31 + (9 + 3 - 1) = 42$$
$$A_3 = 12 + 9 = 21$$
$$B_3 = 72 + 9 = 81$$
$$C_3 = 42 + 9 = 51$$
$$A_4 = 1 + 9 = 10$$
$$B_4 = 61 + 9 = 70$$
$$C_4 = 31 + 9 = 40$$

Between A_1 and A_2 and between A_3 and A_4 there are spp - 1 = 2 short-front-pitch coils; between A_2 and A_4 there are 2 x spp = 6 normal-front-pitch coils; and between A_3 and C_1, C_3 and B_1, B_3 and A_1 there are

$$\frac{90}{3} - 4 \times \text{spp} = 30 - 12 = 18 \text{ normal-front-pitch coils}$$

This is in accordance with the Connection Table 6-4 for retrogressive winding and spp = 3. Conductors $A_1, A_4, B_1, B_4, C_1, C_4$ are lower conductors, and conductors A_2, A_3, B_2, B_3, C_2, C_3 are upper conductors. (See page 273).

Example 2

14-pole rotor with 147 slots and retrogressive (SP) connection. spp = 3 1/2, back pitch = 11, front pitch = 10 slot pitches (see Eq. 6-1). The beginning of phase A lies in slot 1. The beginning of phase B lies in one of the slots $(1 + 2 \times 3\,1/2) + \frac{2 \times 147}{14} \times \text{integer} = 8 + 21 \times \text{integer}$, where the integer 0, 1, 2, 3, 4, 5 or 6, i.e., the beginning of phase B can lie in one of the slots 8, 29, 50, 71, 92, 113, or 134 (see Eq. 6-2). The beginning of phase C can lie in one of the slots (1 + 4 x 3 1/2) + 21 x integer = 15, 36, 57, 78, 99, or 120. For equal spacing, the beginning of the 3 phases should lie in slots 1, 1 + $\frac{147}{3}$ = 50, and 1 + 2 x $\frac{147}{3}$ = 99. Therefore, the start of phase B will be put in slot 50 and that of phase C in slot 99. The Conductor Distribution Table 6-31 or 6-32 shows that these slots can be chosen as beginnings of the phases, since slot 50 has the same polarity as slot 8 and slot 99 has the same polarity as slot 15. The formula (6-3b) yields for the other leads of the 3 phases:

$A_2 = 1 + (11 + 3\ 1/2 - 1\ 1/2) = 14$

$B_2 = 50 + (11 + 3\ 1/2 - 1\ 1/2) = 63$

$C_2 = 99 + (11 + 3\ 1/2 - 1\ 1/2) = 112$

$A_3 = 14 + (11 - 1) = 24$

$B_3 = 63 + (11 - 1) = 73$

$C_3 = 112 + (11 - 1) = 122$

$A_4 = 1 + 11 = 12$

$B_4 = 50 + 11 = 61$

$C_4 = 99 + 11 = 110$

Between A_1 and A_2, there are (spp - 1/2) = 3 short-front-pitch coils; between A_4 and A_3 there are (spp - 1 1/2) = 2 short-front-pitch coils. Between A_2 and A_4 there are 2 x spp = 7 normal-front-pitch coils. Between A_3 and B_1, B_3 and C_1, C_3 and A_1, there are $\frac{147}{3}$ - 4 x spp = 49 - 14 = 35 normal-front-pitch coils. This is in accordance with Connection Table 6-5 for retrogressive winding and spp = 3 1/2. Conductors A_1, A_4, B_1, B_4, C_1, C_4 are lower conductors. Conductors A_2, A_3, B_2, B_3, C_2, C_3 are upper conductors. (See page 277).

Example 3

6-pole rotor with 54 slots and progressive-retrogressive connection. spp = 3, back pitch = front pitch = 9 (see Eq. 6-1). The beginning of phase B can lie in one of the slots (1 + 2 x 3) + $\frac{2 \times 54}{6}$ x integer = 7 + 18 x integer, where the integer 0, 1, or 2, i.e., in slot 7, 25, or 43, and the beginning of phase C can lie in one of the slots (1 + 4 x 3) + $\frac{2 \times 54}{6}$ x integer = 13 + 18 x integer, where the integer 0, 1, or 2, i.e., in slot 13, 31, or 49 (see Eq. 6-2). For equal spacing, the beginnings of the 3 phases should lie in slots 1, 1 + $\frac{54}{3}$ = 19, and 1 + 2 x $\frac{54}{3}$ = 37. The Conductor-distribution Table 6-30 shows that the slots 19 and 37 do not appear in the series of slots possible for the beginnings of phases B and C (7, 25, 43, and 13, 31, 49, respectively). Therefore, equal spacing is not possible, and two other slots must be chosen. Slot 13 can be chosen for the beginning of phase C, and slot 25 for the beginning of phase B. The position of the other leads can be determined by using the formula 6-3c.

6-5. General Rules for Laying Out a Working Diagram.

In Art. 6-3, many Working Diagrams are given for different number of poles, for different values of spp, and for both the retrogressive (SP) as well as the progressive-retrogressive (LP-SP) connection. The number and the sequence of abnormal- and normal-front pitches in the region of the leads of each phase are determined by the value of spp and kind of connection. They are independent of the number of poles. Figs. 6-113 to 6-116 show the number and sequence of abnormal- and normal-front pitches in phase A for the retrogressive (SP) and the progressive-retrogressive (LP-SP) connections. They also show the beginning and end of the first coil series of phase A. Figs. 6-113 and 6-115 refer to spp = integer. Figs. 6-114 and 6-116 refer to spp = (integer + 1/2).

As explained in Art. 6-4, the number of normal-front-pitch coils between the jumper lead A_3 and the beginning of the next phase for retrogressive (SP) windings (Figs. 6-113 and 6-114) or between A_4 and the beginning of the next phase for progressive-retrogressive (LP-SP) windings (Figs. 6-115 and 6-116) depends upon the number of slots and the number of poles. For 120° mechanical and electrical spacing of leads, the number of normal-front-pitch coils following A_3 for retrogressive (SP) windings, and A_4 for progressive-retrogressive (LP-SP) windings is equal to

$$\frac{\text{No. of slots}}{3} - 4 \times \text{spp}$$

except for windings with 6 poles or a multiple of 6 poles. In these latter cases, other lead spacing must be used, and the number of normal-front-pitch coils between A_3 for retrogressive (SP) windings or A_4 for progressive-retrogressive (LP-SP) windings and the beginning of the next phase depends upon the slot in which the next phase starts.

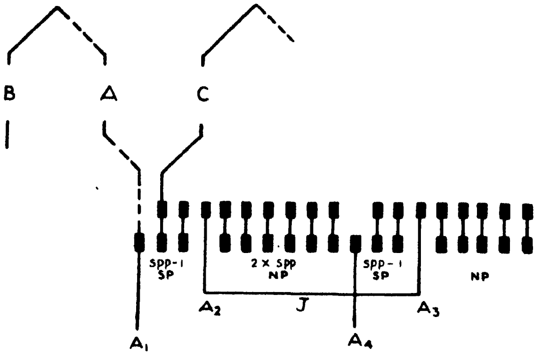


Fig. 6-113. General Working Diagram for determining the start and finish of the first coil series of phase A, and the sequence of coil connections in the vicinity of the leads of phase A for a retrogressive (SP) winding with spp = integer.

Legend: A = Bottom of slot 1.
B = Top of slot (1 + Number of slots - back pitch)
C = Top of slot (1 + back pitch)
SP = Short-front-pitch coil.
NP = Normal-front-pitch coil.
J = Reversing jumper.

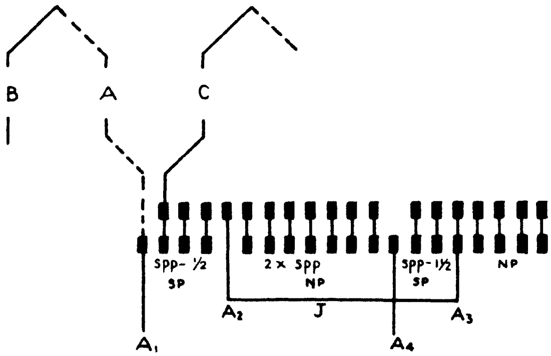


Fig. 6-114. General Working Diagram for determining the start and finish of the first coil series of phase A, and the sequence of coil connections in the vicinity of the leads of phase A for a retrogressive (SP) winding with spp = (integer + 1/2).

Legend: A = Bottom of slot 1.
B = Top of slot (1 + Number of slots - back pitch)
C = Top of slot (= back pitch)
SP = Short-front-pitch coil.
NP = Normal-front-pitch coil.
J = Reversing jumper.

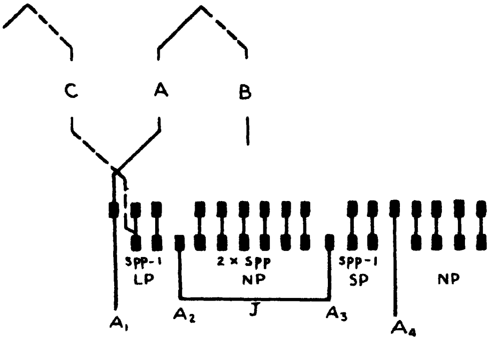


Fig. 6-115. General Working Diagram for determining the start and finish of the first coil series of phase A, and the sequence of coil connections in the vicinity of the leads of phase A for a progressive-retrogressive (LP-SP) winding with spp = integer.

Legend: A = Top of slot 1.
B = Bottom of slot (1 + back pitch)
C = Bottom of slot (1 + Number of slots - back pitch)
SP = Short-front-pitch coil.
NP = Normal-front-pitch coil.
LP = Long-front-pitch coil.
J = Reversing jumper.

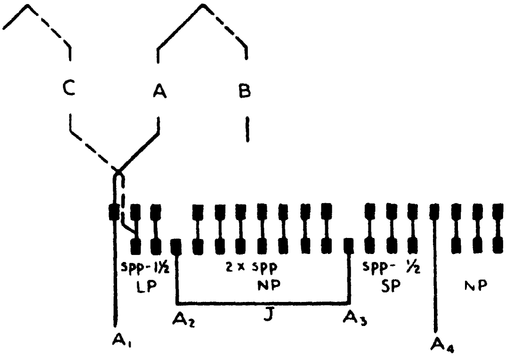


Fig. 6-116. General Working Diagram for determining the start and finish of the first coil series of phase A, and the sequence of coil connections in the vicinity of the leads of phase A for a progressive-retrogressive (LP-SP) winding with spp = (integer + 1/2).

Legend: A = Top of slot 1.
B = Bottom of slot (1 + back pitch)
C = Bottom of slot (2 + Number of slots - back pitch)
SP = Short-front-pitch coil.
NP = Normal-front-pitch coil.
LP = Long-front-pitch coil.
J = Reversing jumper.

The total number of clips at the connection-end of a winding is equal to

No. of coils - 6

The total number of clips for half-turn coils is equal to the total number of clips at the connection end of the winding plus the total number of clips at the end opposite the connection end. The number of clips at the end opposite the connection end is equal to the number of coils. Figs. 6-113 to 6-116, as well as the foregoing considerations, refer to phase A. They apply also to phases B and C.

The same examples will be considered as in Art. 6-3.

Example 1

10-pole rotor with 90 slots and a retrogressive (SP) winding. Fig. 6-34, Fig. 6-113, and Connection Table 6-4 apply to this case. Table 6-4 shows that the back pitch is equal to 9 slot pitches. Fig. 6-113 shows that A_1, the start of the first coil series of phase A, lies in the bottom of slot 1 and connects by back pitch = 9 with upper conductor 1 + 90 - 9 = 82. Fig. 6-113 also shows that the end of the first coil series lies in upper slot 1 + 9 = 10 and connects to lower conductor 2. It also shows, as well as does Table 6-4, that there are (spp - 1) = 2 short-front-pitch-coils between A1 and the upper jumper lead A_2. Following A_2, there are 2 x spp = 2 x 3 = 6 normal-front-pitch coils between A_2 and the lower lead A_4. Following A_4, there are 2 more short-front-pitch coils and this is followed by the upper jumper lead A_3. Connection Table 6-4 shows that following A_3 there are 18 coils between A_3 and the start of the next phase C_1. The Table also shows the coil connection sequence following C_1 and then B_1 from which the Working Diagram Fig. 6-34 is obtained.

Example 2

14-pole rotor with 147 slots and a retrogressive (SP) connection. Fig. 6-46, Fig. 6-114, and Connection Table 6-5 apply to this case. Table 6-5 shows that the back pitch is equal to 11 slot pitches. Fig. 6-114 shows that A_1, the start of the first coil series of phase A, lies in the bottom of slot 1 and connects by back pitch = 11 with upper (1 + 147 - 11) = 137. Fig. 6-114 also shows that the end of the first coil series is upper conductor of slot 1 + 11 = 12 and connects to the lower conductor 2. It also shows, as well as does Table 6-5, that there are (spp - 1/2) = 3 1/2 - 1/2 = 3 short-front-pitch coils between A_1 and the upper jumper lead A_2. Following A_2, there are 2 x 3 1/2 = 7 normal-front-pitch coils between A_2 and the lower lead A_4. Following A_4 there are now (spp - 1 1/2) = (3 1/2 - 1 1/2) = 2 short-front-pitch coils and this is followed by the upper jumper lead A_3. Connection Table 6-4 shows that following A_3 there are 35 normal-front-pitch coils between A_3 and the start of the next phase B_1. The Table also shows the coil connection sequence following B_1 and then C_1 from which the Working Diagram Fig. 6-46 is obtained.

Example 3

6-pole rotor with 54 slots and a progressive-retrogressive (LP-SP) connection. Fig. 6-67, Fig. 6-115, and Connection Table 6-16 apply to this case. The Connection Table shows that the back pitch is equal to 9 slot pitches. Following the directions of Fig. 6-115, the start and end of the first coil series of phase A are fixed. It shows that upper conductor A_1 connects by back pitch = 9 with lower conductor 10, and that the end of the coil series is lower conductor of slot 46 which connects with upper conductor 2. Following A_1 there are 2 long-front-pitch coils, lower jumper lead A_2, 6 normal-front-pitch coils, lower jumper lead A_3, 2 short-front-pitch coils, and finally upper lead A_4. Table 6-16 shows that the foregoing coil sequence is true also for phases B and C. Since the number of poles is 6, the spacing between A_1, B_1, and C_1 is not equal, and the number of coils between A_4 and C_1, C_4 and B_1, and B_4 and A_1 depends upon the slot in which C_1 and B_1 start. One solution is shown by Table 6-16 which shows that there are no coils between A_4 and C_1, and C_4 and B_1, but that 18 normal-front-pitch coils lie between B_4 and A_1. Working Diagram 6-67 is developed in this way.

Fig. 6-117 shows a photograph of the connection end of a 210 slot rotor prior to the application of the reversing jumpers and leads.

6-6. Wave Winding with More Than 2 Conductors Per Slot. In the foregoing, the windings with 2 conductors per slot, one in each layer, were considered. A conductor may consist of 2 parallel straps, insulated together or separately, but with ends connected by the same clip. In general, all straps which lie in

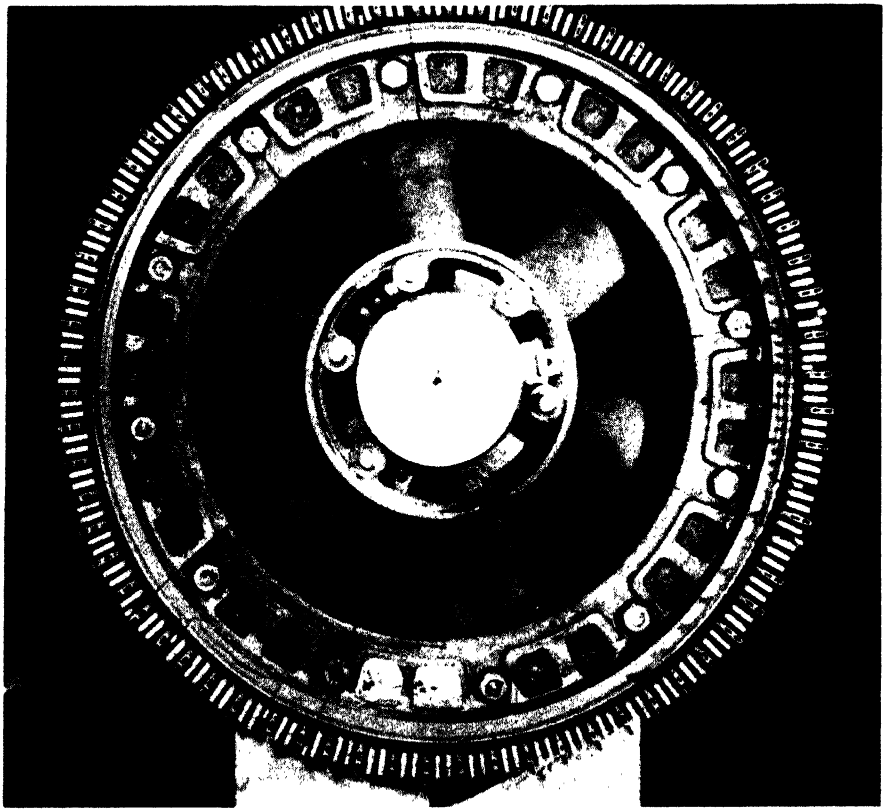


Fig. 6-117. Lead end of a 210-slot rotor connected for 14 poles with spp = 5. Progressive-retrogressive (LP-SP) winding with 2 conductors per slot. Note the 2 different kinds of clips; the commonly used solid clips and the long ones looking like a figure 8 and used as fan blades. At 3 symmetrical places there are 4 conductors, 2 of which are to be connected by a jumper and the other 2 are the beginning and end, respectively, of a phase.

the same clip make a single conductor. Thus, if there are more than 2 conductors per slot, i.e., 2 or 3 conductors per layer, the number of clips will be increased as if there were more slots with only 2 conductors, one per layer. For example, a 6-pole rotor with 54 slots and 2 conductors in each layer has the same number of coils and clips as a 6-pole rotor with 108 slots and 1 conductor in each layer. Hence, a winding with more than one conductor per layer can be treated as a one which has a fictitious number of slots equal to the

Real number of slots X Conductors per layer

and a fictitious spp equal to the

Real spp X Conductors per layer

If the 6-pole winding of the example with 54 slots, i.e., spp = 3, had 2 conductors per layer, it would be represented by the Connection Table 6-22 for spp = 3 x 2 = 6 with 54 x 2 = 108 slots. The Working Diagram for this winding is the same as for 6 poles and 108 slots, i.e., spp = 6. Note that the number found in this way in the Connection and Conductor-distribution Tables and in the Working Diagrams refer to conductors and not to slots, i.e., in windings with more than 2 conductors per layer, the upper or lower conductors and not the slots are to be numbered by the consecutive digits, 1, 2, 3, 4, etc.

A practical example is given in Figs. 6-118 and 6-119, which show a wound rotor having a star-connected retrogressive winding with 2 coil sides per slot per layer. The rotor has 90 slots and is connected for 8 poles. The fictitious number of slots is equal to 90 x 2 = 180, and the fictitious spp is equal to $\frac{90}{3 \times 8} \times 2 = 7\ 1/2$. This can be checked by noting that there are (spp - 1/2) = (7 1/2 - 1/2) = 7 coils (clips) following a lead; that there are 2 x spp = 2 x 7 1/2 = 15 clips between the jumper lead (A_2) and the star lead (A_4); that there are (spp - 1 1/2) = (7 1/2 - 1 1/2) = 6 clips between star lead A_4 and the remaining jumper lead A_3; and finally that there are $\frac{\text{No. of coils}}{3} - 4 \times \text{spp} = \frac{180}{3} - 4 \times 7\ 1/2 = 30$ clips between the lead A_3 and the beginning of the next phase. Fig. 6-118 shows the entire lead connection end, and Fig. 6-119 shows the coil connections near the leads of one phase and also shows the 2 coils per slot per layer.

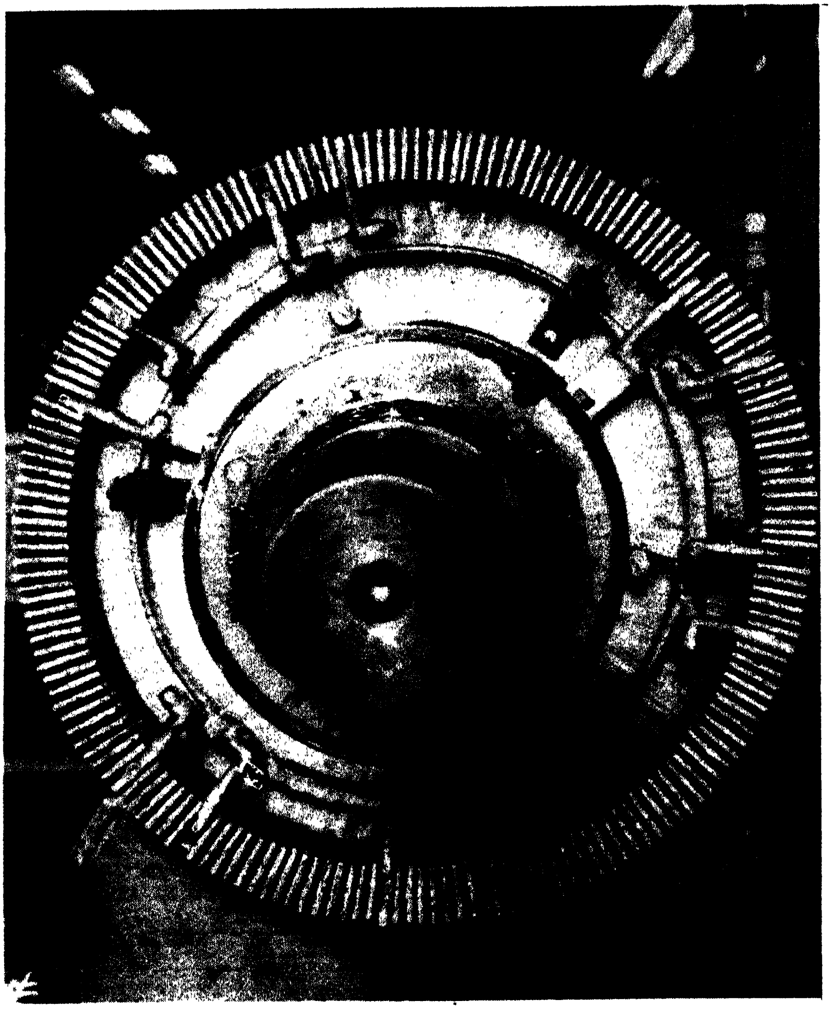


Fig. 6-118. Lead end of a 90-slot rotor connected for 8 poles. Retrogressive winding with 2 conductors per slot per layer.

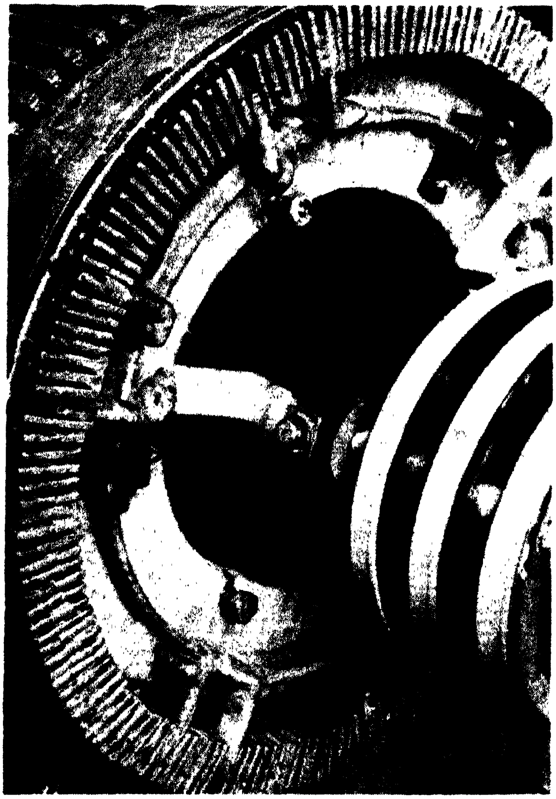


Fig. 6-119. Close-up of coil connections in vicinity of the leads of the rotor winding of Fig. 6-118. Note 2 coils per slot per layer.

6-7. Series Star and Series Delta Connection of Phases.

In Figs. 6-5, 6-6, 6-9, 6-10, as well as in the Working Diagrams, both parts of each phase are connected by the reversing jumper placing all coils of each phase in series. From these diagrams, the series star connection can be readily obtained by connecting the ends of the 3 phases (A_4, B_4, C_4) to a star point (Fig. 6-120). The beginnings of the phases (A_1, B_1, C_1) are connected either to slip rings or to lines. The series delta connection (Fig. 6-121) is obtained by connecting the end of phase A (A_4) with the beginning of phase B (B_1), the end of phase B (B_4) with the beginning of phase C (C_1), and the end of phase C (C_4) with the beginning of phase A (A_1); or the end of phase A (A_4) with the beginning of phase C (C_1), the end of phase C (C_4) with the beginning of phase B (B_1), and the end of phase B (B_4) with the beginning of phase A (A_1), whichever makes possible the shortest connection between phases. The corner points of the delta are connected either to slip rings or to lines.

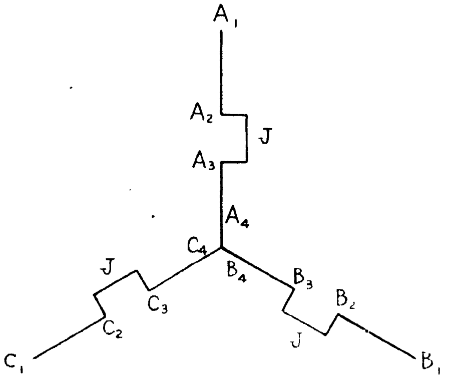


Fig. 6-120. Schematic diagram for the series star connection of the parts of the winding.

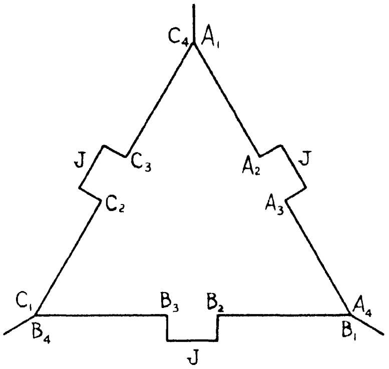


Fig. 6-121. Schematic diagram for the series delta connection of the parts of the winding.

Both series star and series delta connections are tabulated in Table 6-42.

6-8. Two Parallel Star and 2 Parallel Delta Connections.

The 2 parallel star and the 2 parallel delta connection can be obtained easily by opening the reversing jumper and connecting both parts of each phase in parallel. Fig. 6-122 shows the 2 parallel star connection. The beginnings of each 2 parts A_1 and

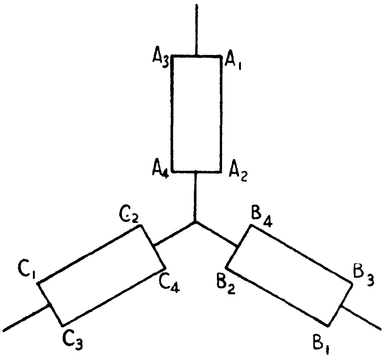


Fig. 6-122. Schematic diagram of a 2-parallel star connection for spp = integer.

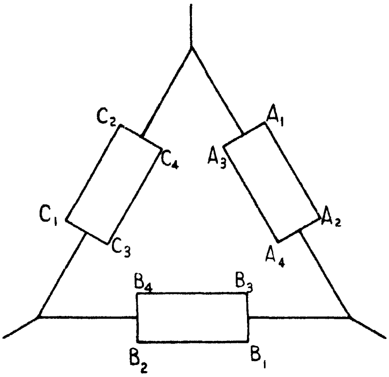


Fig. 6-123. Schematic diagram of a 2-parallel delta connection for spp = integer.

A_3, B_1 and B_3, and C_1 and C_3 are respectively connected together and also the ends of each 2 parts, A_2 and A_4, B_2 and B_4, and C_2 and C_4 are respectively connected together. The ends of $A_2 \rightarrow A_4$, $B_2 \rightarrow B_4$, and $C_2 \rightarrow C_4$ are connected to the star point, while the beginnings $A_1 \rightarrow A_3$, $B_1 \rightarrow B_3$, and $C_1 \rightarrow C_3$ are connected to the slip rings or lines.

Fig. 6-123 shows the 2 parallel delta connection. The 2 parts of each phase are connected in the same way as for 2 parallel stars. Then the ends $A_2 \rightarrow A_4$ of phase A are connected with the beginnings $B_1 \rightarrow B_3$ of phase B, the ends $B_2 \rightarrow B_4$ of phase B with the beginnings $C_1 \rightarrow C_3$ of phase C, and finally the ends $C_2 \rightarrow C_4$ of phase C with the beginnings $A_1 \rightarrow A_3$ of phase A. The corner points of the delta are connected either to slip rings or to lines. Both parallel star and parallel delta connections are tabulated in Table 6-42.

Note that the placing in parallel of the 2 parts of each phase by opening the reversing jumper applies only to spp = integer. When spp = (integer + 1/2), both parts of each phase have different numbers of coil series (see for example, Fig. 6-9) and, therefore, cannot be connected in parallel. The parallel connection of windings with spp = (integer + 1/2) is treated in Art. 6-10.

6-9. Integral-slot Windings with More than 2 Parallel Circuits. When spp is an integer, the maximum possible number of parallel circuits is equal to the number of poles, just as in the case of the lap winding. Any other number of parallel circuits chosen must be such that the number of poles is divisible by this number.

It has been explained in Art. 6-8 that in the case spp = integer, 2 parallel circuits can be obtained by placing in parallel both parts of each phase (see Figs. 6-122 and 6-123). Therefore, if a larger number of parallels than 2 is desirable, each part must be divided in parallel paths. The maximum possible number of parallel paths in each part is equal to $\left(\frac{\text{No. of poles}}{2}\right)$. If $\left(\frac{\text{No. of poles}}{2}\right)$ is larger than and divisible by the number of desirable parallel paths, all parallel paths can be arranged in each part and both parts connected in series. If $\left(\frac{\text{No. of poles}}{2}\right)$ is not divisible by the number of desirable paths, then the 2 parts must be connected in parallel and each part can have only one-half of the desired number of parallel paths. For example, if 10 parallel paths are desirable in a 20-pole winding, either each part must be divided into 10 parallel paths and both parts connected in series, or each part must be divided in 5 parallel paths and both parts connected in parallel. If 4 parallel paths are desired, this can be achieved only by dividing each part in 2 parallel paths and connecting both parts in parallel. On the other hand, if 5 parallel paths are desirable, this can be achieved only by arranging 5 parallel paths in each part and connecting the 2 parts in series. If the maximum number of parallel paths which is equal to the number of poles (in the example, 20) is desirable, then each part must be arranged in $\left(\frac{\text{No. of poles}}{2}\right)$ parallel paths, and the 2 parts connected in parallel. For the same number of desirable parallel paths, different arrangements are often possible. The arrangement with the smallest number of jumpers should be used. This will be explained in the discussion of the examples.

In order to determine the conductors which belong to each parallel path in each part of the phase, the following procedure, which will be applied to phase A, can be used:

(a) Use the Conductor Distribution Table for the upper conductors and write, beginning with the starting upper conductor of the phase, the upper conductors which lie under all poles of same polarity as the polarity of the starting conductor. For example, for phase A, start with upper conductor 1 and write all the upper conductors lying under the odd poles, since phase A starts under pole 1. The conductors have to be written in $\left(\frac{\text{No. of poles}}{2}\right)$ horizontal rows with spp conductors in each row.

(b) Start the first parallel path of the first part of the phase with the conductor in which the phase starts. In phase A, this is the upper conductor 1.

(c) Divide $\left(\frac{\text{No. of poles}}{2}\right)$ by the number of desirable parallel paths in the part. The quotient, which must be an integer, determines the number of conductors in each column to be connected in series.

(d) Add to the starting conductor the number (2 x back pitch) and find this number in the same column, but in the second horizontal row. To this number again add (2 x back pitch) and find this new number in the same column, but in the third horizontal row. Repeat until the number of conductors in the starting column is equal to the quotient determined under (c). If the quotient is equal to 1, this number of conductors in the first column reduces to 1, namely, to the starting conductor.

(e) Add to the last conductor determined under (d), (2 x back pitch + 1) and find this number in a column other than the column containing the starting conductor and also in a different horizontal row. Add to this conductor (2 x back pitch), and find this number in the same column. Continue with adding (2 x back pitch) the same number of times as before and then add (2 x back pitch + 1) to find a conductor in the next column. Continue this procedure until the quotient determined under (c) x spp conductors has been determined. These conductors belong to the first parallel path of the first part. If the quotient is equal to 1, there belongs to this path in each column only 1 conductor.

(f) Start the second parallel path with the first conductor of the (quotient + 1) -th horizontal row, the third parallel path with the (2 x quotient + 1) -th horizontal row, and so on, and determine for each path the quotient x spp conductors.

(g) Repeat for the second part of the phase the same procedure as for the first part, using the upper conductors not contained in the first part.

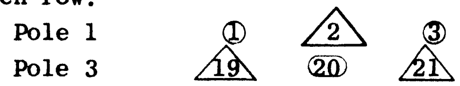
The method will be applied to several examples.

Example 1. A 4-pole winding with 36 slots, i.e., spp = 3, and 4 parallel paths.

Here both parts of the phase must be connected in parallel and each part must consist of 2 parallel paths. It follows from the Conductor Distribution Table 6-30 that the first part of phase A contains the following upper conductors under the first and third poles

Pole #1	Pole #3
1 2 3	19 20 21

Arranged in $\left(\frac{\text{No. of poles}}{2}\right) = \frac{4}{2} = 2$ horizontal rows with spp = 3 conductors in each row.



Since the quotient of $\left(\frac{\text{No. of poles}}{2}\right)$ and the number of parallel paths in the part is equal to 1, only one conductor of each column belongs to each path.

The upper conductors belonging to the 2 parallel paths of the first part are indicated by circles and triangles, respectively.

The back pitch is 3 x 3 = 9 slot pitches; (2 x back pitch + 1) = 2 x 9 + 1 is equal to 19. The starting conductor is 1. Therefore, the first parallel path consists of the upper conductors

$$1, \quad 1 + 19 = 20, \quad 20 + 19 = 39 - 36 = 3$$

The lower conductors belonging to the first parallel path are automatically determined by the back pitch; for clockwise winding, and left-hand coils, upper 1 connects with lower 1 + 9 = 10; lower 10 connects with upper 20, upper 20 connects with lower 20 + 9 = 29; and lower 29 connects with upper 3 which connects to lower 3 + 9 = 12. The path progresses through spp = 3 coils, and this ends the first path of the first part. The starting conductor of the second path of the first part is 19 and the upper conductors belonging to this path are 19, 19 + 19

= 38 - 36 = 2, 2 + 19 = 21. Again the path progresses through spp = 3 coils,

upper 19 → lower 28 → upper 2 → lower 11 → upper 21 → lower 30

Fig. 6-124 shows phase A of this winding. A_1 and A_2 are the beginning and end of the first parallel path of the first part; A_3 and A_4 are the beginning and end of the second parallel path of this part. The beginnings A_1 and A_3 lie in upper conductors. The remaining upper conductors of phase A belong to the second part of this phase. These are the conductors

10-11-12   28-29-30

which lie under the even poles, and arranged again in two horizontal rows with three conductors in each row,

Pole 2 = ⑩ 11⃤ ⑫
Pole 4 = 28⃤ ㉙ 30⃤

The first parallel path of the second part, indicated by circles, starts in upper conductor 10 and contains the upper conductors

10, 10 + 19 = 29, 29 + 19 = 48 - 36 = 12

The path progresses through spp = 3 coils,

upper 10 → lower 19 → upper 29 → lower 2 → upper 12 → lower 21

This completes the first path of the second part.

The second parallel path, indicated by triangles, starts in upper conductor 28. It contains the upper conductors

28, 28 + 19 = 47 - 36 = 11, 11 + 19 = 30

and follows the path

upper 28 → lower 1 → upper 11 → lower 20 → upper 30 → lower 3

This completes the second path of the second part. The corresponding lower conductors are determined by the back pitch. Each path progresses through spp = 3 coils (Fig. 6-124). Connecting all paths in parallel completes the 4-parallel connection desired.

Example 2. An 8-pole winding with 72 slots and 8 or 4 parallel circuits.

For 8 poles and 72 slots, spp = 3 and back pitch = 9 slot pitches. The Conductor Distribution Table 6-30 shows that the first part of phase A contains the following upper conductors under the odd poles

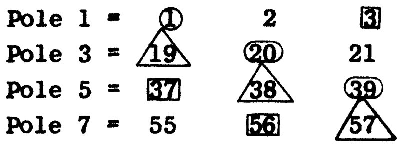


Chart A

(a) 8-parallel paths. For 8 parallel paths, the quotient of $\left(\frac{\text{No. of poles}}{2}\right)$ and the number of parallel paths in the part is equal to 1. Therefore, only 1 conductor of each column belongs to each path.

The first parallel path starts with the upper conductor 1 and contains the upper conductors

1, 1 + (2 x back pitch + 1) = 1 + 19 = 20, 20 + 19 = 39

The second path starts with the upper conductor 19 and contains the upper conductors

19, 19 + 19 = 38, 38 + 19 = 57

The third path starts with the upper conductor 37 and contains the upper conductors

37, 37 + 19 = 56, 56 + 19 = 75 - 72 = 3

and the fourth path starts with upper conductor 55 and contains the upper conductors

55, 55 + 19 = 74 - 72 = 2, 2 + 19 = 21

The lower conductors are determined by the back pitch = 9. So the lower conductors of the first part are

1 + 9 = 10, 20 + 9 = 29, 39 + 9 = 48

Each parallel path progresses through only 3 coils, i.e., 6 poles, because spp = 3.

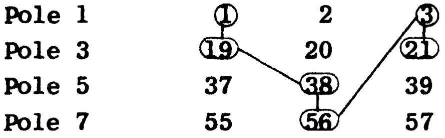
The remaining upper conductors of phase A, i.e., those lying under the even poles, belong to the second part of this phase. The conductors belonging to each of the 4 parallel paths can be determined in the same manner as for the first part.

If 8 parallel paths are desirable, the 4 parallel paths of the first part and the 4 parallel paths of the second part are to be connected in parallel.

(b) 4 parallel paths. If only 4 parallel paths are desired, either the 4 parallel paths of the first part are to be connected in series with the 4 parallel paths of the second part, or the 4 parallel paths of each part are to be connected in series in pairs and the pairs of one part connected in parallel with the pairs of the other part, or each of the 4 parallel paths of the first part is to be connected in series with one of the 4 parallel paths of the second part. Marking the polarities of the ends and beginnings of the paths is the best way to find out how the parts are to be connected in series or parallel (see Fig. 6-124).

However, the number of jumpers per phase is reduced when the 4 parallel paths are achieved by arranging 2 parallel paths in each part and connecting the 2 parts in parallel as shown below. In this case, 2 conductors lying in the same column are connected in series and each parallel path of each part goes through 2 x spp coils. This is shown in Chart B.

Chart B



Pole 1	①	2	③
Pole 3	⑲	20	㉑
Pole 5	37	㊳	39
Pole 7	55	(56)	57

The first parallel path starts with upper conductor 1 and contains the upper conductors:

1, 1 + 2 x back pitch = 1 + 18 = 19,
19 + (2 x back pitch + 1) = 19 + 19 = 38,
38 + (2 x back pitch) = 38 + 18 = 56,
56 + 19 = 75 - 72 = 3, 3 + 18 = 21

The second parallel paths starts with upper conductor 37 and contains the upper conductors

37, 55, 2, 20, 39, and 57.

Each parallel path goes through 2 x spp = 6 coils. The remaining upper conductors of phase A, i.e., those lying under the even poles, belong to the second part of this phase, and are to be arranged in 2 parallel paths in the same manner as that shown for the odd poles. The 2 parallel paths of the first part are then connected in parallel to the 2 parallel paths of the second part, thus accomplishing the 4 parallel paths.

Example 3. A 20-pole winding with 300 slots arranged for either 20, 10, 5, or 4 parallel paths.

For this winding, spp = 5 and the back pitch is equal to 15 slot pitches.

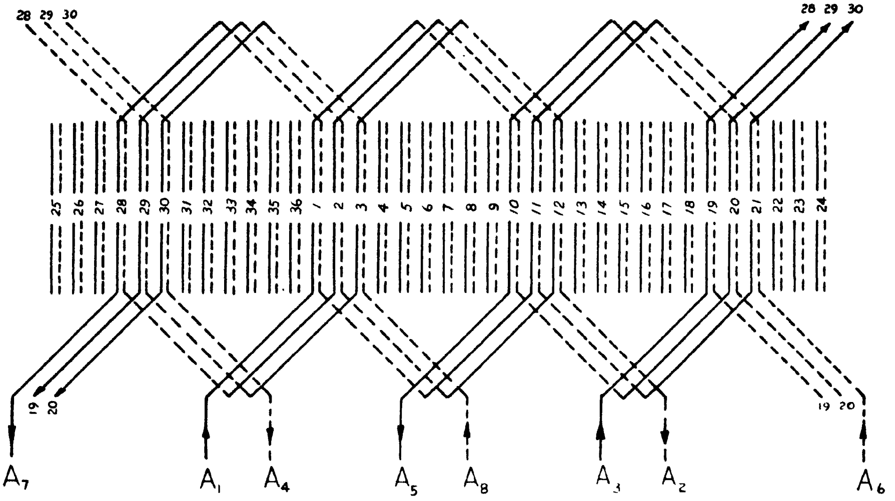


Fig. 6-124. 36-Slot, 4-pole, 4-parallel path winding with spp = integer. Phase A only.

Connect $A_1 \rightarrow A_3 \rightarrow A_6 \rightarrow A_8$ together and $A_2 \rightarrow A_4 \rightarrow A_5 \rightarrow A_7$ together.

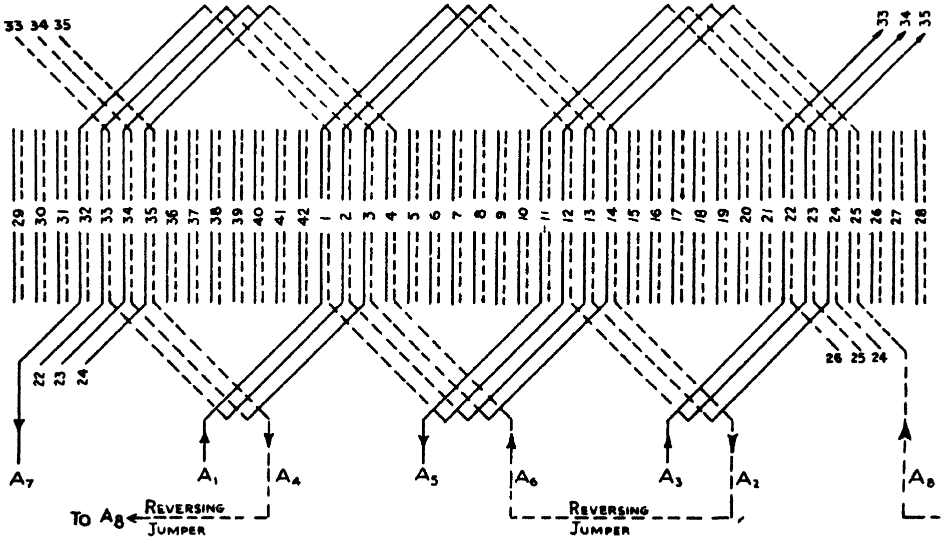


Fig. 6-125. 42-Slot, 4-pole, 2-parallel path winding with spp = (integer + $\frac{1}{2}$). Phase A only.

Connect $A_1 \rightarrow A_3$ together and $A_5 \rightarrow A_7$ together

(a) 20 parallel paths. The quotient of $\left(\frac{\text{No. of poles}}{2}\right)$ and the parallel circuits in the part is equal to 1. Therefore, only 1 conductor of each column belongs to each path. Each part has 10 parallel paths and the 2 parts are connected in parallel. The first part of phase A contains the following upper conductors under the odd poles

Chart A

Pole 1	1	2	3	4	5
Pole 3	31	32	33	34	35
Pole 5	61	62	63	64	65
Pole 7	91	92	93	94	95
Pole 9	121	122	123	124	125
Pole 11	151	152	153	154	155
Pole 13	181	182	183	184	185
Pole 15	211	212	213	214	215
Pole 17	241	242	243	244	245
Pole 19	271	272	273	274	275

The first parallel path starts in upper conductor 1 and contains the upper conductors

1, 1 + (2 x back pitch + 1) = 1 + 31 = 32,
32 + 31 = 63, 63 + 31 = 94, 94 + 31 = 125

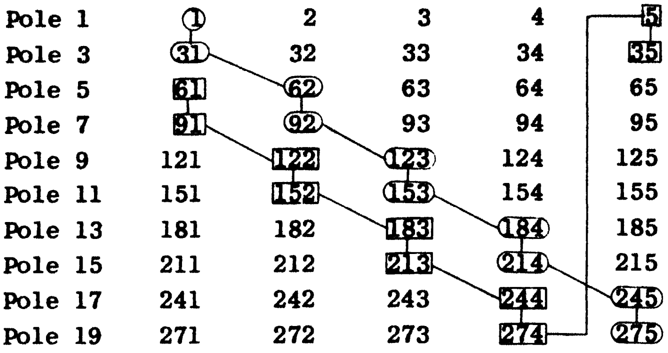
The path is indicated by circles. The other 9 paths in the part start in upper conductors 31, 61, 91, 121, 151, 181, 211, 241, and 271, respectively, and follow the pattern set by adding (2 x back pitch + 1) to each conductor.

The conductors belonging to each of the 10 parallel paths of the second part can be determined in the same manner as for the first part.

(b) 10 parallel paths. There are two possibilities for connecting the winding for 10 parallel paths. Either each part is divided into 10 parallel paths and both parts are connected in series, or each part is divided into 5 parallel paths and both parts are connected in parallel.

If the first method is adopted, then the procedure is the same as that shown under (a) and the two parts are connected in series. If the second method is adopted, then each part is divided into 5 parallel paths and the procedure is as shown in Chart B. The upper conductors under the odd poles are

Chart B


Pole 1 1 2 3 4 5
Pole 3 31 32 33 34 35
Pole 5 61 62 63 64 65
Pole 7 91 92 93 94 95
Pole 9 121 122 123 124 125
Pole 11 151 152 153 154 155
Pole 13 181 182 183 184 185
Pole 15 211 212 213 214 215
Pole 17 241 242 243 244 245
Pole 19 271 272 273 274 275

The $\left(\frac{\text{No. of poles}}{2}\right)$ divided by the desirable number of parallel paths (5) in the part is 2. Therefore, in accordance with the rules outlined above, there will belong to each path 2 conductors in each column and there will be 2 x spp (2 x 5 = 10) conductors per parallel path. The first parallel path of the first part starts in upper conductor 1 and contains the upper conductors

1, 1 + (2 x back pitch) = 1 + 30 = 31,
31 + (2 x back pitch + 1) = 31 + 31 = 62,
62 + 30 = 92, 92 + 31 = 123,
123 + 30 = 153, 153 + 31 = 184, 184 + 30 = 214,
214 + 31 = 245, 245 + 30 = 275.

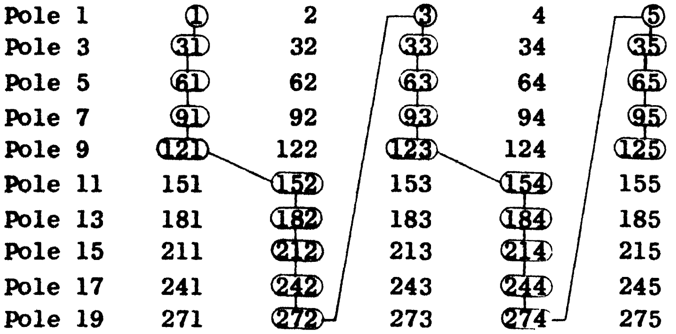
The path is indicated by circles.

The second parallel path of the first part starts in horizontal row 1 + 2 = 3, or with upper conductor 61. The part is indicated by squares. Similarly, the remaining three paths in the part start with upper conductors 121, 181, and 241 respectively. The conductors belonging to each of the 5 parallel paths of the second part can be determined in the same way as for the first part.

(c) 5 parallel paths. For 5 parallel paths in the winding, each part must be divided into 5 parallel paths and the two parts connected in series. The procedure is exactly the same as that shown in Chart B.

(d) 4 parallel paths. The only method to achieve 4 parallel paths in the winding is to divide each part into 2 parallel paths and to connect the 2 parts in parallel. (Each part cannot be connected in 4 parallel paths because $\left(\frac{\text{No. of poles}}{2}\right) = 10$ is not divisible by 4.) Then, $\left(\frac{\text{No. of poles}}{2}\right)\frac{1}{2} = \frac{20}{2 \times 2} = 5$. Thus, the number of conductors in the same column connected in series is equal to 5 and the number of conductors per parallel path = 5 x 5 = 25. The upper conductors under the odd poles are shown in Chart C.

Chart C


Pole 1 ① 2 ③ 4 ⑤
Pole 3 ㉛ 32 ㉝ 34 ㉟
Pole 5 (61) 62 (63) 64 (65)
Pole 7 (91) 92 (93) 94 (95)
Pole 9 (121) 122 (123) 124 (125)
Pole 11 151 (152) 153 (154) 155
Pole 13 181 (182) 183 (184) 185
Pole 15 211 (212) 213 (214) 215
Pole 17 241 (242) 243 (244) 245
Pole 19 271 (272) 273 (274) 275

The first path of the first part starts in upper conductor 1 and contains the upper conductors

1, 1 + (2 x back pitch) = 1 + 30 = 31,
31 + 30 = 61, 61 + 30 = 91, 91 + 30 = 121,
121 + (2 x back pitch + 1) = 121 + 31 = 152,
152 + 30 = 182, etc.

The path contains 25 conductors. The second parallel path starts in upper conductor 151 in the sixth (= 1 + 5) horizontal row.

The conductors belonging to each parallel path of the second part can be determined in the same manner as for the first part.

6-10. (Integral + 1/2) - Slot Windings with 2 or more than 2 Parallel Circuits. It has been explained previously (see Art. 6-8) that both parts of a wave winding with spp = (integer + 1/2) cannot be connected in parallel since they have different numbers of coils. Parallel paths can be arranged only in each part separately. Both parts must have the same number of parallel paths and the parallel paths of one part must be connected in series with the parallel paths of the other part. Therefore, the maximum possible number of parallel paths is $\left(\frac{\text{No. of poles}}{2}\right)$.

Both parts are to be treated in the same manner as are the windings with spp = integer (see Art. 6-9). However, (2 x back pitch) and not (2 x back pitch + 1) is to be added under rules (d) and (e) when the quotient of $\left(\frac{\text{No. of poles}}{2}\right)$ and the number of parallel paths in the part is equal to 1; (2 x back pitch - 1) instead of (2 x back pitch) and (2 x back pitch) instead of (2 x back pitch + 1) are to be used under paragraphs (d) and (e), respectively, when the quotient is different from 1. Both cases will be explained by examples.

Example 1. A 4-pole winding with 42 slots and 4 parallel circuits. spp = 3 1/2 and back pitch = 11 slot pitches.

Since the quotient of $\left(\frac{\text{No. of poles}}{2}\right)$ and the number of parallel paths in the part is equal to 1, only 1 conductor of each column belongs to each path. It follows from Fig. 6-10 or from Conductor Distribution Table 6-31 that the first part of phase A contains the following upper conductors under the first and third poles

Pole 1 = ① △2 ③
Pole 3 = △22 ㉓ △24

i.e., the first path of the first part contains the following upper conductors

1, 1 + (2 x 11) = 23, 23 + 22 = 45 - 42 = 3

and follows the path

upper 1→lower 12→upper 23→lower 34→upper 3→lower 14

The second path has the following upper conductors

22, 22 + 22 = 44 - 42 = 2, 2 + 22 = 24

and follows the path

upper 22→lower 33→upper 2→lower 13→upper 24→lower 35

The second part of phase A contains the following upper conductors under the second and fourth poles

Pole 2 = ⑪ △12 ⑬ △14
Pole 4 = △32 ㉝ △34 ㉟

i.e., the first path of the second part contains the following upper conductors

11, 11 + 22 = 33, 33 + 22 = 55 - 42 = 13, 13 + 22 = 35

and follows the path

upper 11→lower 22→upper 33→lower 2→
upper 13→lower 24→upper 35→lower 4

The second path has the following upper conductors

32, 32 + 22 = 54 - 42 = 12, 12 + 22 = 34,
34 + 22 = 56 - 42 = 14

and follows the path

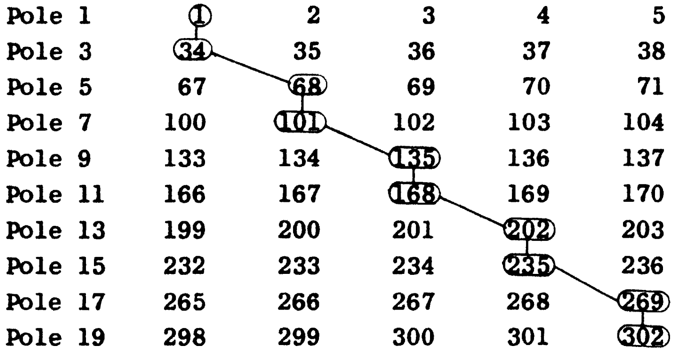
upper 32 → lower 1 → upper 12 → lower 23 →
upper 34 → lower 3 → upper 14 → lower 25 →

Each path of the first part must be connected in series by a reversing jumper with one path of the second part. That is, lower 14 must be connected with lower 4, and lower 35 must be connected with lower 25. Fig. 6-125 shows phase A of this winding. The parallel paths of the first part go through 3 coils each; the parallel paths of the second part go through 4 coils each. Two reversing jumpers connect the paths of the first part with the paths of the second part.

Example 2. A 20-pole winding with 330 slots and 5 parallel circuits. spp = 5 1/2 and the back pitch = 17 slot pitches.

The Conductor Distribution chart for phase A contains the following upper conductors under the odd poles

Chart A



Pole 1	1	2	3	4	5
Pole 3	34	35	36	37	38
Pole 5	67	68	69	70	71
Pole 7	100	101	102	103	104
Pole 9	133	134	135	136	137
Pole 11	166	167	168	169	170
Pole 13	199	200	201	202	203
Pole 15	232	233	234	235	236
Pole 17	265	266	267	268	269
Pole 19	298	299	300	301	302

Since the quotient of $\left(\frac{\text{No. of poles}}{2}\right)$ and 5 is equal to 2, 2 conductors of each column belong to each path.

The first path of the first part contains the upper conductors

1, 1 + (2 x back pitch - 1) = 1 + (2 x 17 - 1) = 34
34 + (2 x back pitch) = 68,
68 + 33 = 101, 101 + 34 = 135, etc.

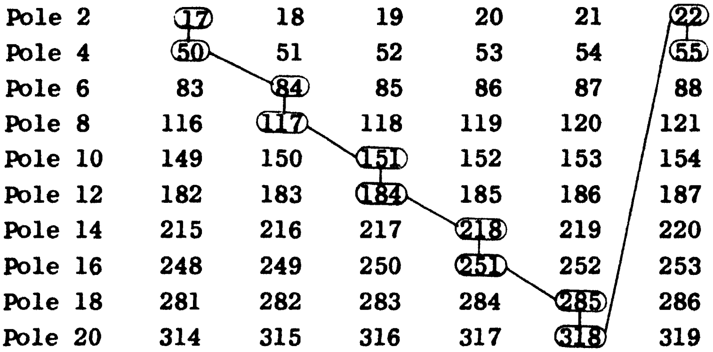
The second path contains the upper conductors

67, 100, 134, 167, 201, 234, 268, 301, 5, 38

The third path starts with upper conductor 133; the fourth path with upper conductor 199; and the fifth path with upper conductor 265.

The second part of phase A contains the following upper conductors under the even poles

Chart E



Pole 2	17	18	19	20	21	22
Pole 4	50	51	52	53	54	55
Pole 6	83	84	85	86	87	88
Pole 8	116	117	118	119	120	121
Pole 10	149	150	151	152	153	154
Pole 12	182	183	184	185	186	187
Pole 14	215	216	217	218	219	220
Pole 16	248	249	250	251	252	253
Pole 18	281	282	283	284	285	286
Pole 20	314	315	316	317	318	319

The first path of the second part contains the upper conductors

17, 17 + 33 = 50, 50 + 34 = 84, 84 + 33 = 117, etc.

The remaining four paths start in upper conductors

83, 149, 215, and 281, respectively.

The 5 parallel paths of the first part can be connected by a ring to the 5 parallel paths of the second part, or the first parallel path can be connected by a reversing jumper to the first parallel path of the second part, etc. Five reversing jumpers connect then the 5 paths of the first part with the 5 paths of the second part. The parallel paths of the first part progress through 10 coils each, the parallel paths of the second part progress through 12 coils each.

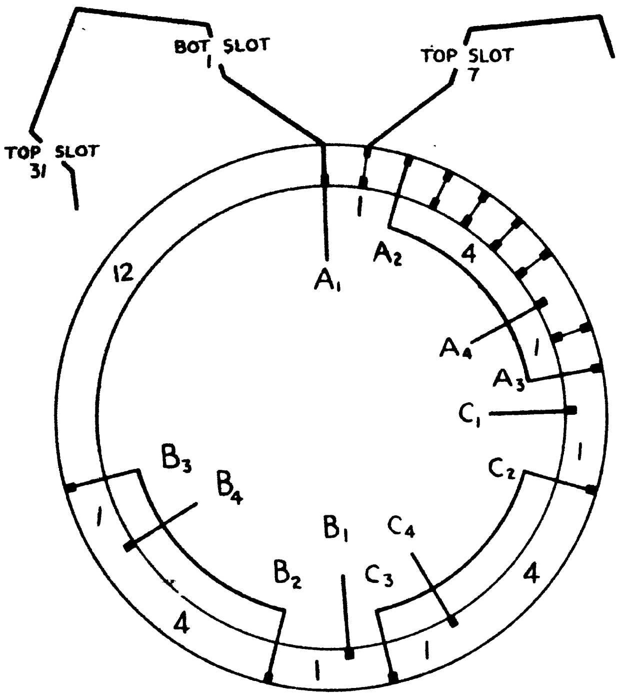


Fig. 6-17. Working diagram of a retrogressive (SP) connection for 36 slots, 6 poles, and spp = 2.

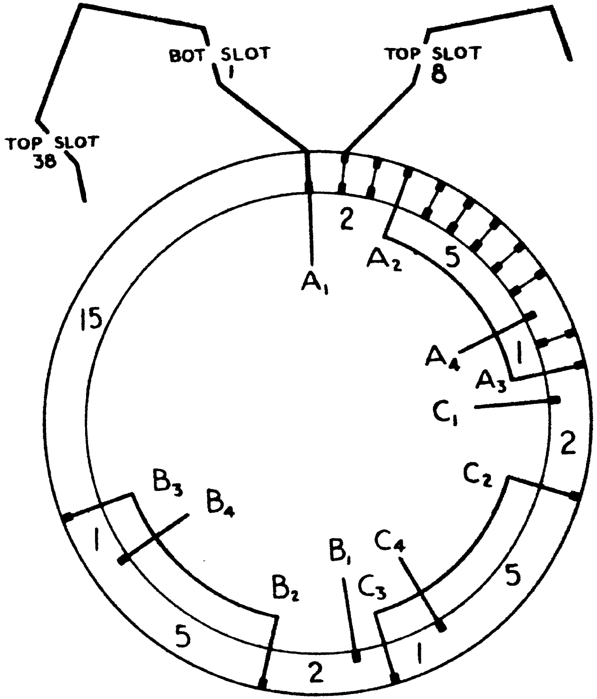


Fig. 6-18. Working diagram of a retrogressive (SP) connection for 45 slots, 6 poles, and spp = 2 1/2.

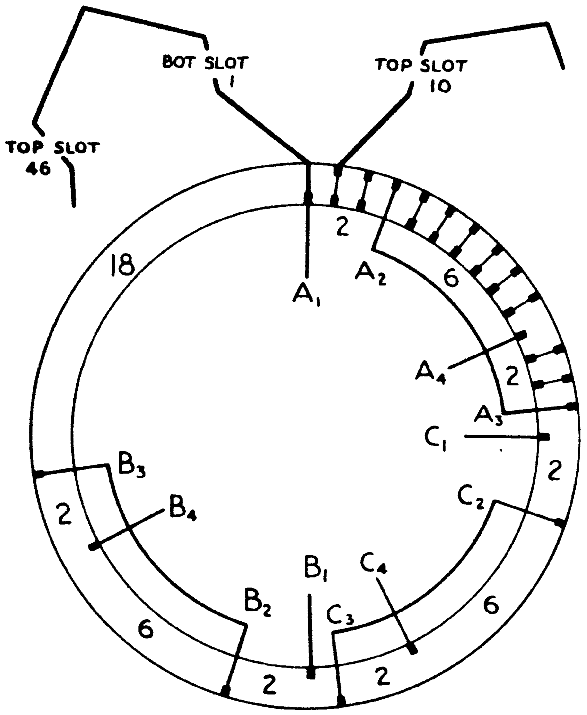


Fig. 6-19. Working diagram of a retrogressive (SP) connection for 54 slots, 6 poles, and spp = 3.

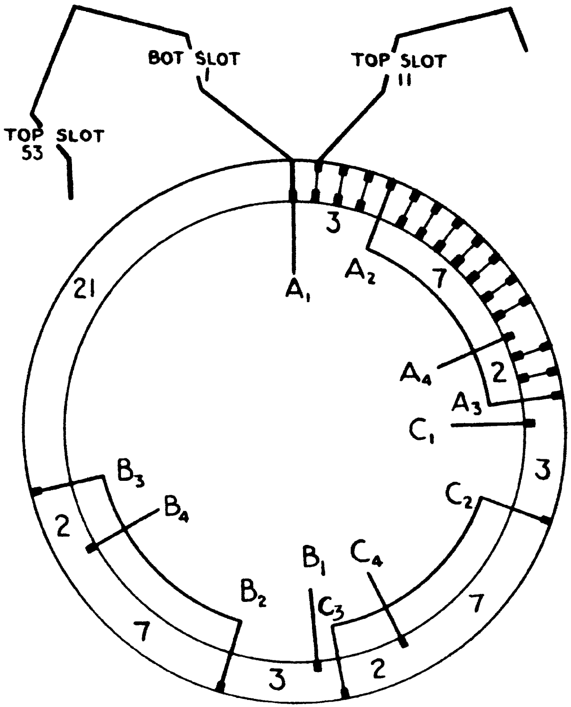


Fig. 6-20. Working diagram of a retrogressive (SP) connection for 63 slots, 6 poles, and spp = 3 1/2.

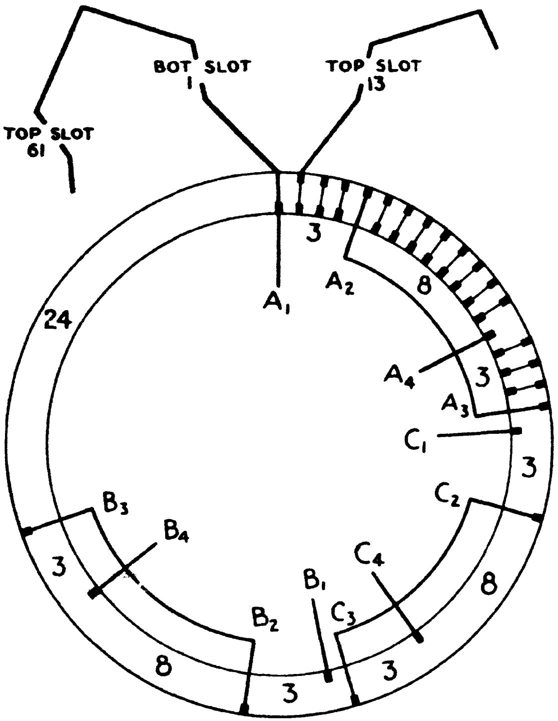


Fig. 6-21. Working diagram of a retrogressive (SP) connection for 72 slots, 6 poles, and spp = 4.

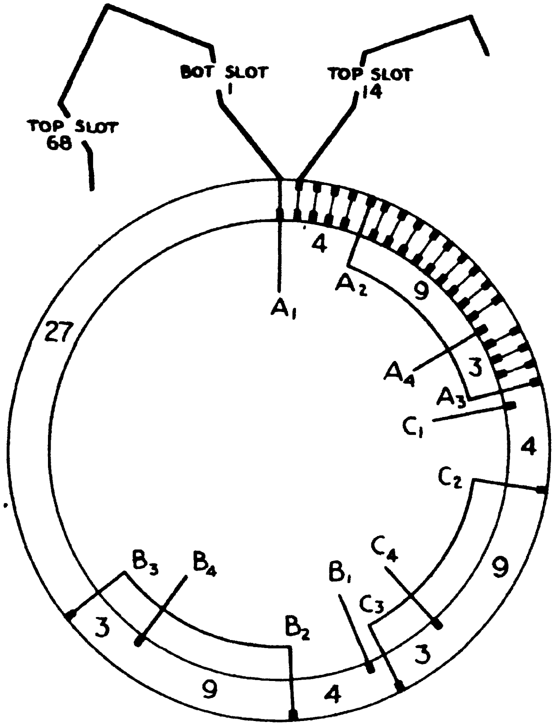


Fig. 6-22. Working diagram of a retrogressive (SP) connection for 81 slots, 6 poles, and spp = 4 1/2.

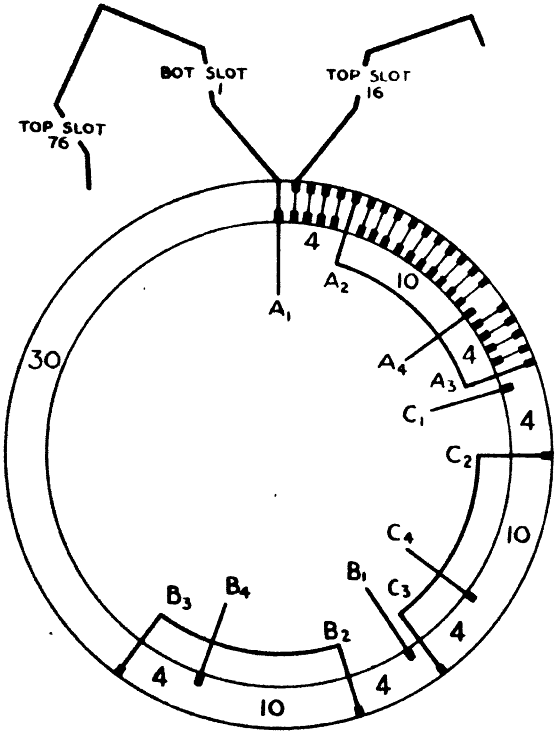


Fig. 6-23. **Working diagram of a retrogressive (SP) connection for 90 slots, 6 poles, and spp = 5.**

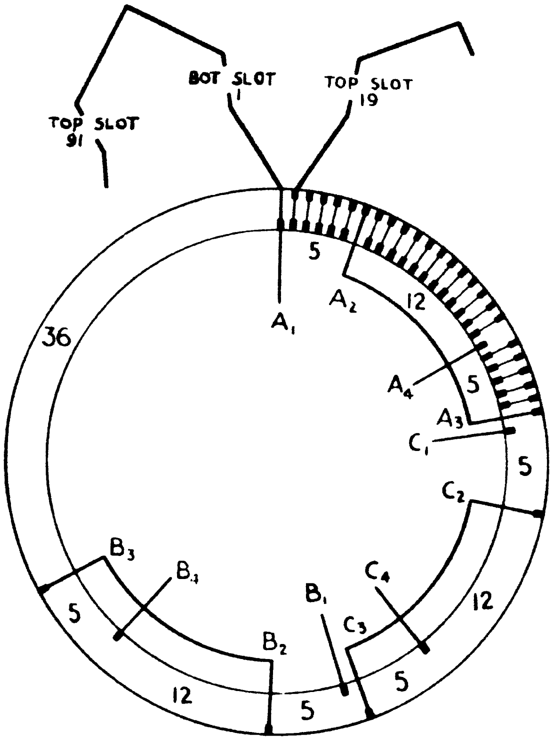


Fig. 6-24. **Working diagram of a retrogressive (SP) connection for 108 slots, 6 poles, and spp = 6.**

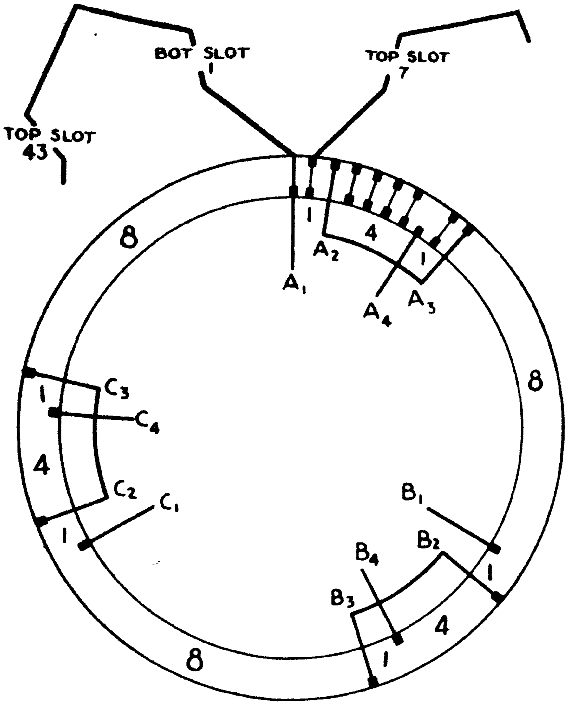


Fig. 6-25. Working diagram of a retrogressive (SP) connection for 48 slots, 8 poles, and spp = 2.

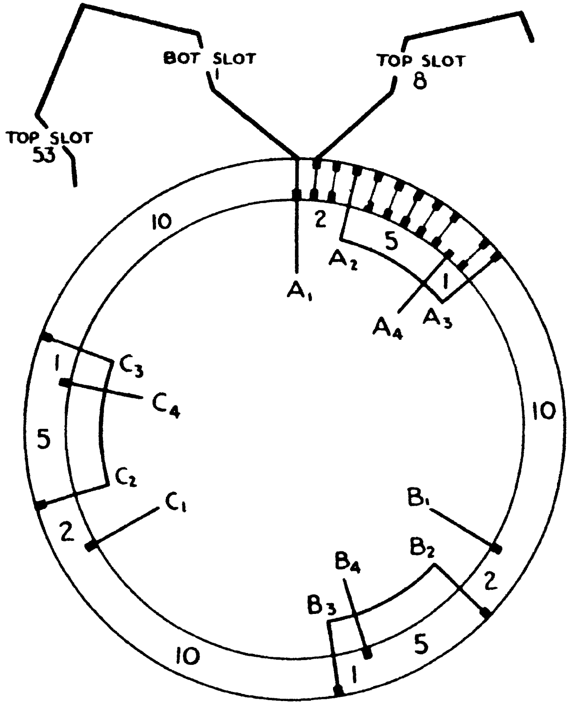


Fig. 6-26. Working diagram of a retrogressive (SP) connection for 60 slots, 8 poles, and spp = 2 1/2.

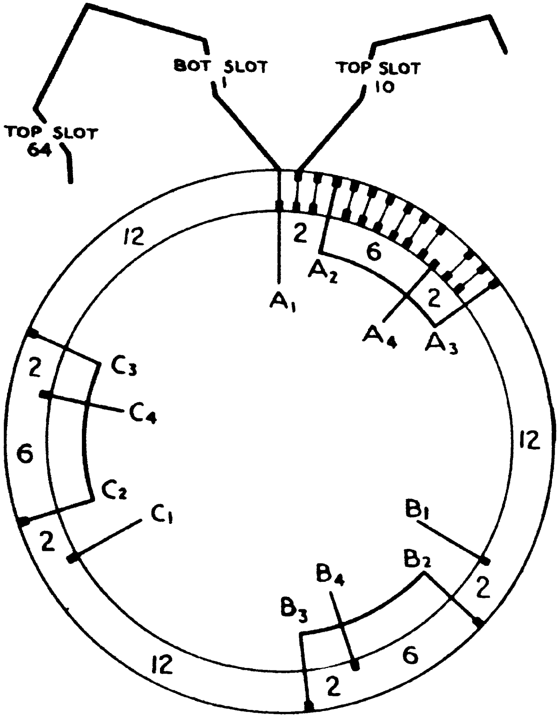


Fig. 6-27. Working diagram of a retrogressive (SP) connection for 72 slots, 8 poles, and spp = 3.

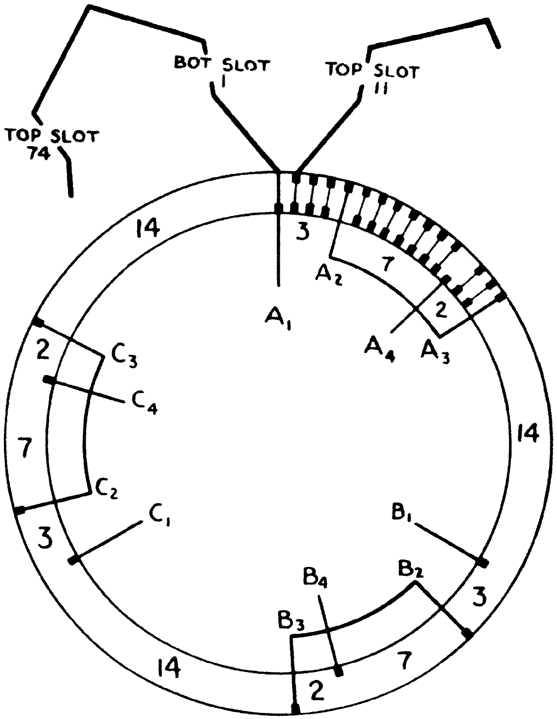


Fig. 6-28. Working diagram of a retrogressive (SP) connection for 84 slots, 8 poles, and spp = 3 1/2.

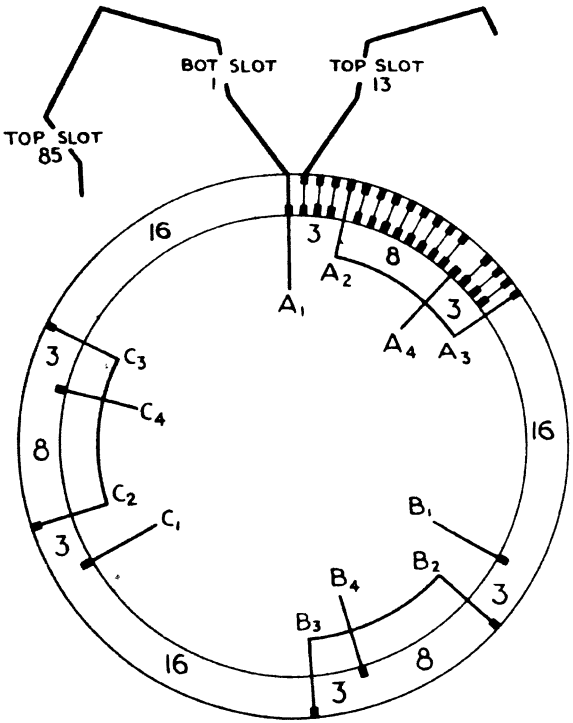


Fig. 6-29. Working diagram of a retrogressive (SP) connection for 96 slots, 8 poles, and spp = 4.

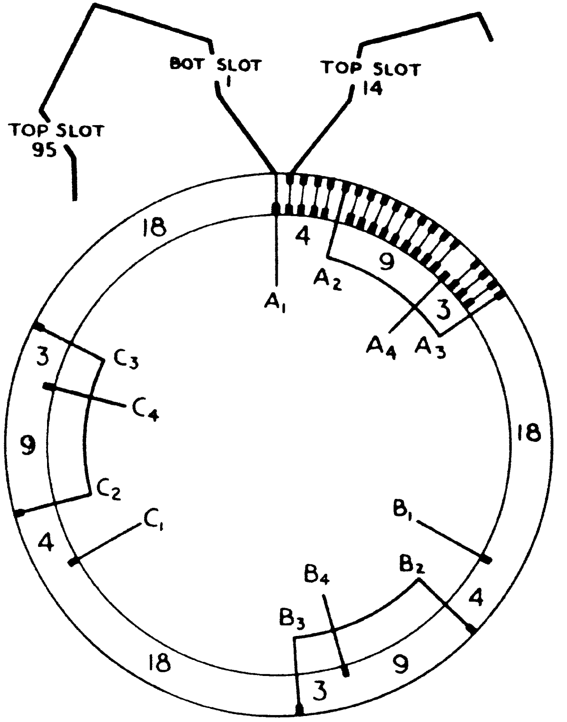


Fig. 6-30. Working diagram of a retrogressive (SP) connection for 108 slots, 8 poles, and spp = 4 1/2.

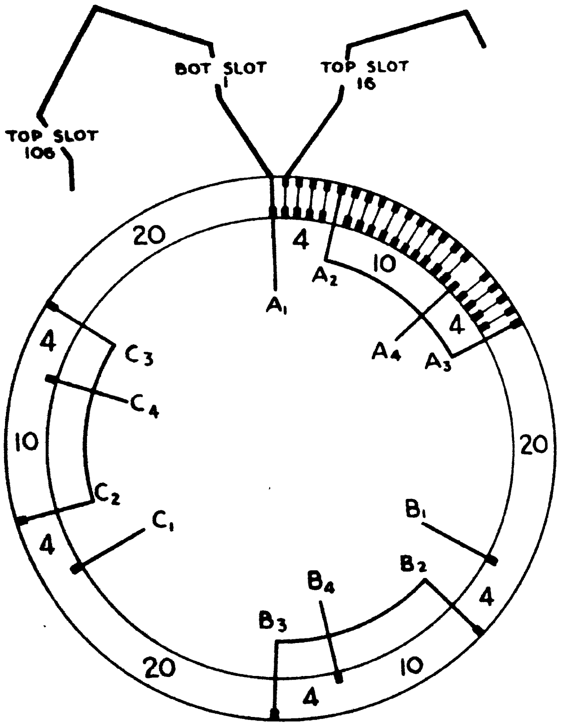


Fig. 6-31. Working diagram of a retrogressive (SP) connection for 120 slots, 8 poles, and spp = 5.

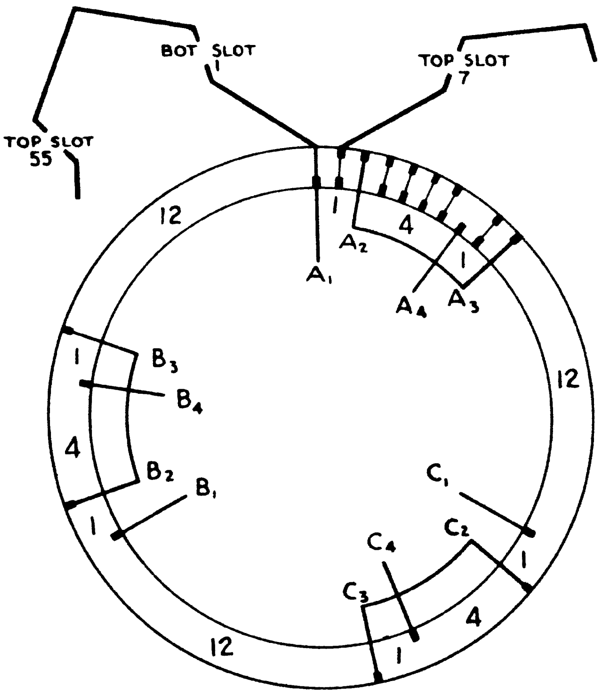


Fig. 6-32. Working diagram of a retrogressive (SP) connection for 60 slots, 10 poles, and spp = 2.

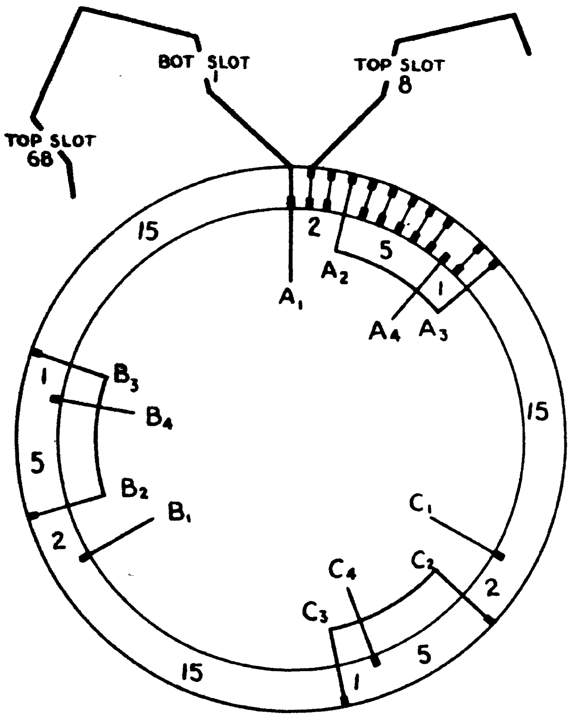


Fig. 6-33. Working diagram of a retrogressive (SP) connection for 75 slots, 10 poles, and spp = 2 1/2.

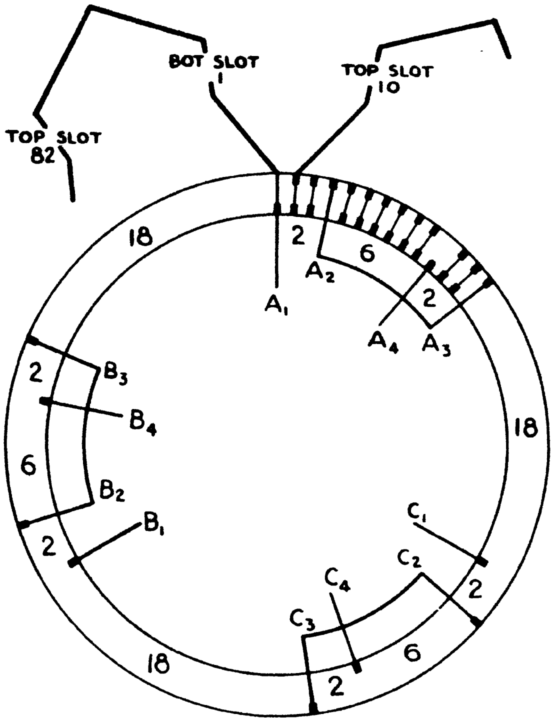


Fig. 6-34. Working diagram of a retrogressive (SP) connection for 90 slots, 10 poles, and spp = 3.

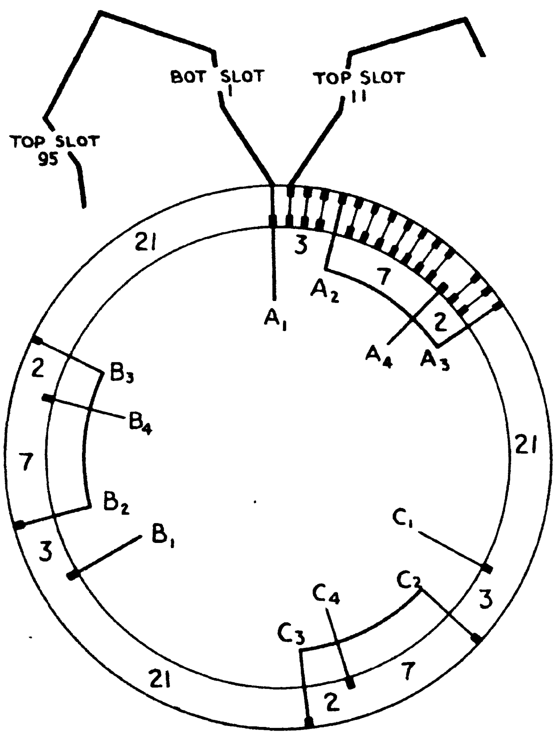


Fig. 6-35. Working diagram of a retrogressive (SP) connection for 105 slots, 10 poles, and spp = 3 1/2.

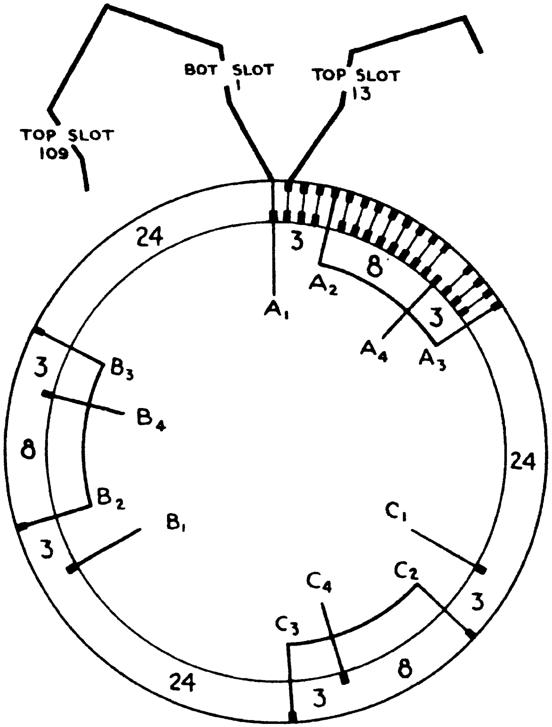


Fig. 6-36. Working diagram of a retrogressive (SP) connection for 120 slots, 10 poles, and spp = 4.

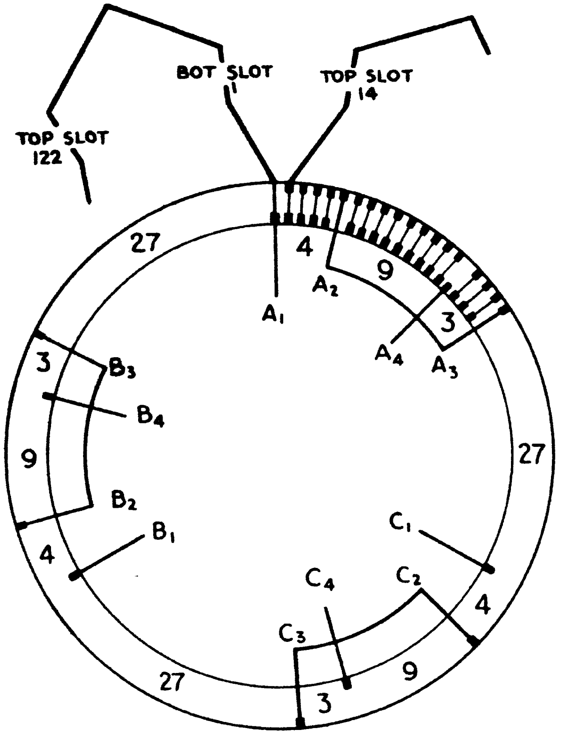


Fig. 6-37. Working diagram of a retrogressive (SP) connection for 135 slots, 10 poles, and spp = 4 1/2.

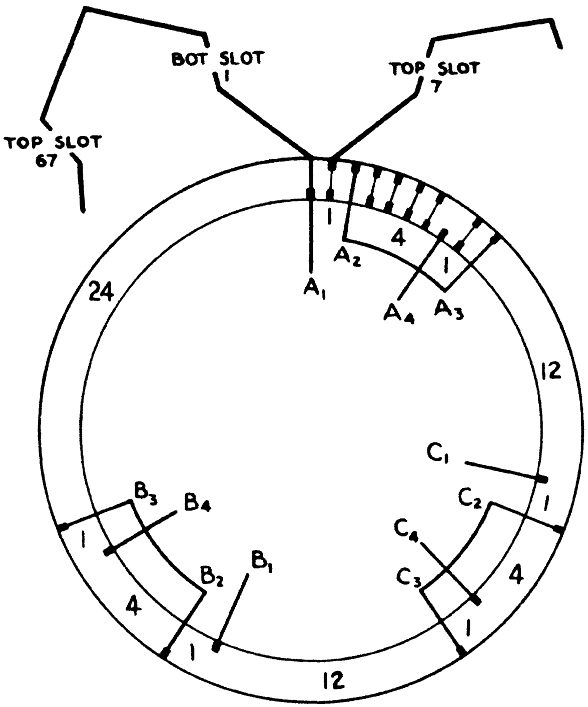


Fig. 6-38. Working diagram of a retrogressive (SP) connection for 72 slots, 12 poles, and spp = 2.

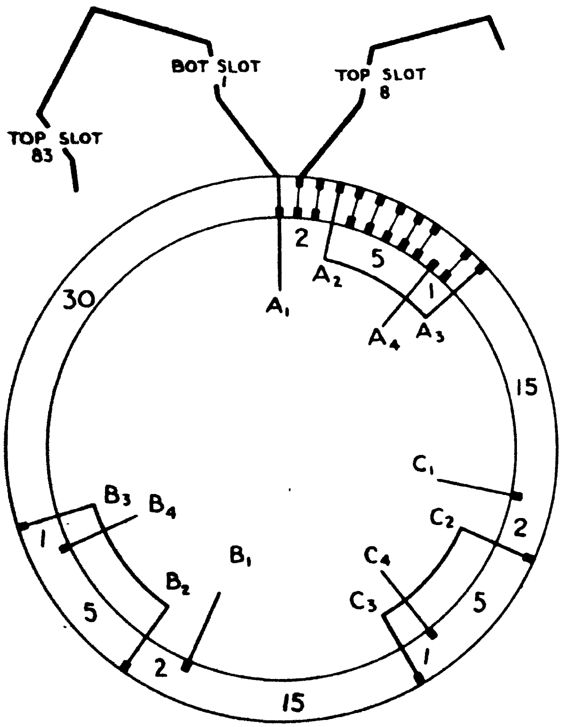


Fig. 6-39. Working diagram of a retrogressive (SP) connection for 90 slots, 12 poles, and spp = 2 1/2.

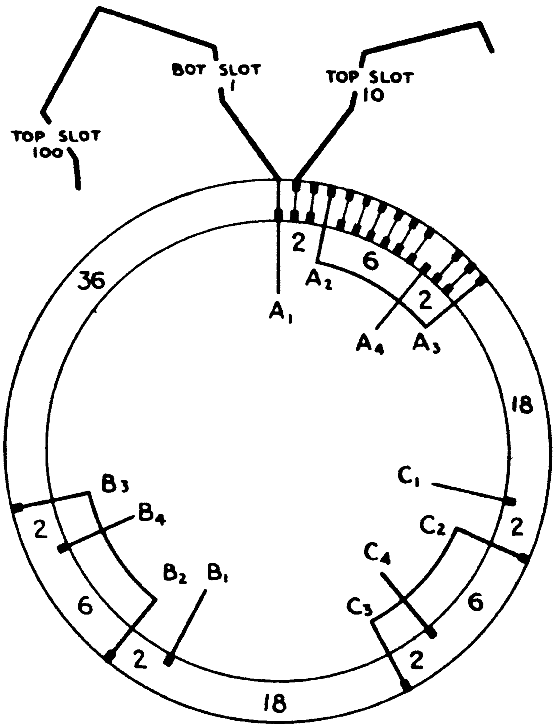


Fig. 6-40. Working diagram of a retrogressive (SP) connection for 108 slots, 12 poles, and spp = 3.

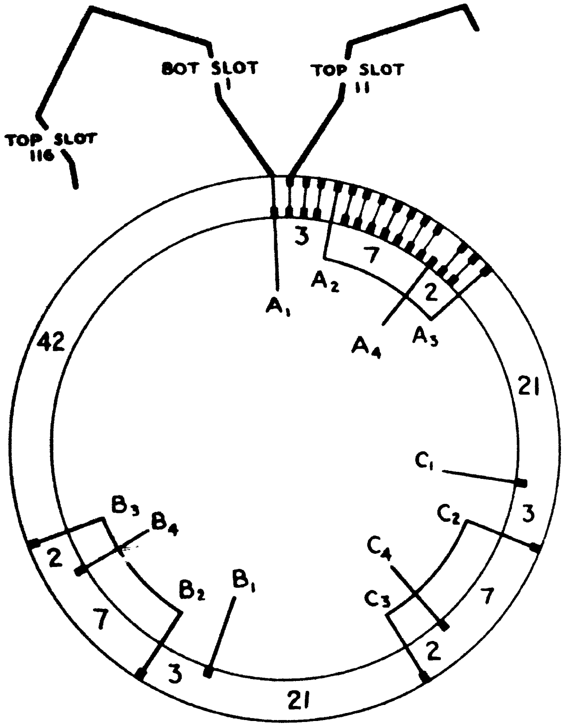


Fig. 6-41. Working diagram of a retrogressive (SP) connection for 126 slots, 12 poles, and spp = 3 1/2.

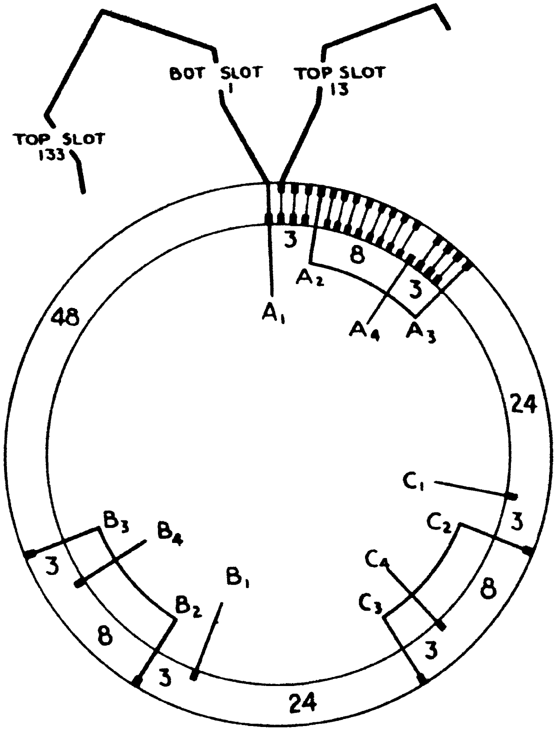


Fig. 6-42. Working diagram of a retrogressive (SP) connection for 144 slots, 12 poles, and spp = 4.

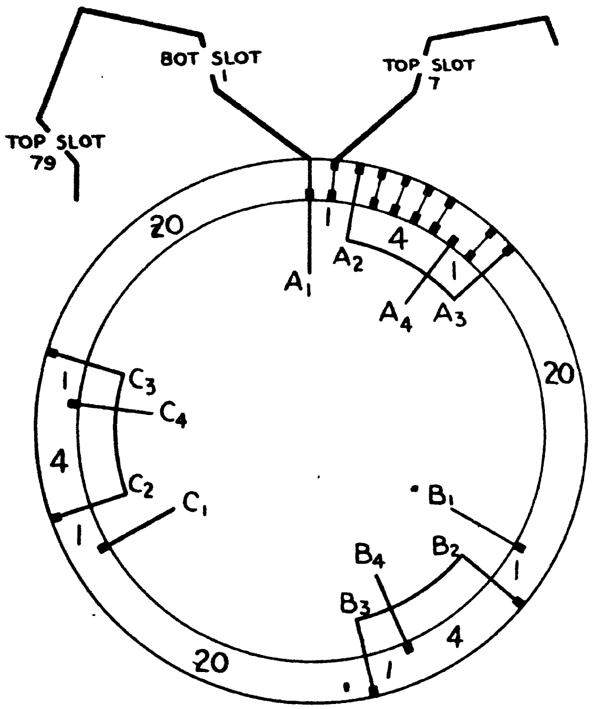


Fig. 6-43. Working diagram of a retrogressive (SP) connection for 84 slots, 14 poles, and spp = 2.

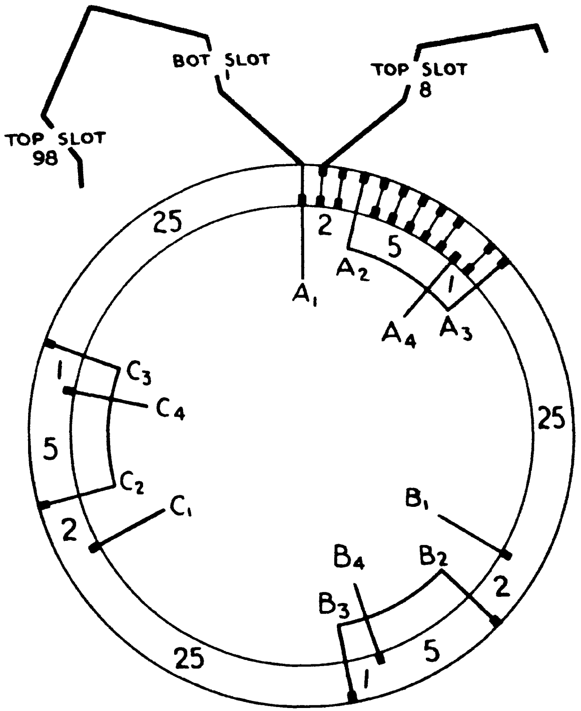


Fig. 6-44. Working diagram of a retrogressive (SP) connection for 105 slots, 14 poles, and spp = 2 1/2.

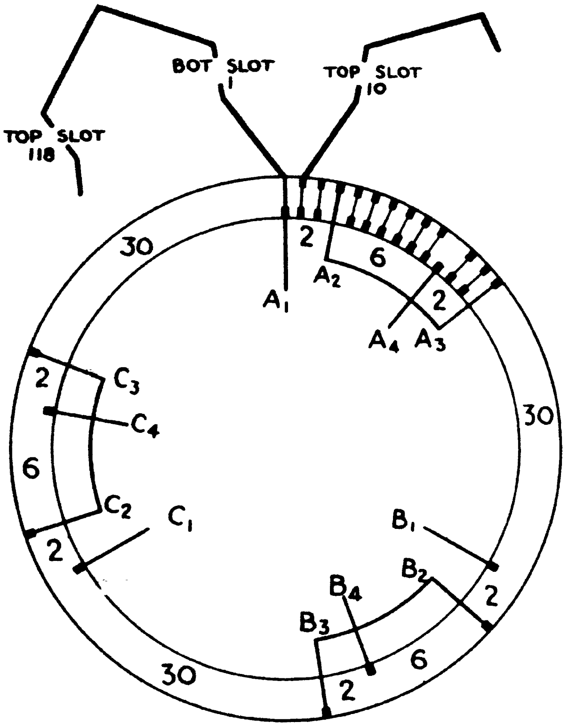


Fig. 6-45. Working diagram of a retrogressive (SP) connection for 126 slots, 14 poles, and spp = 3.

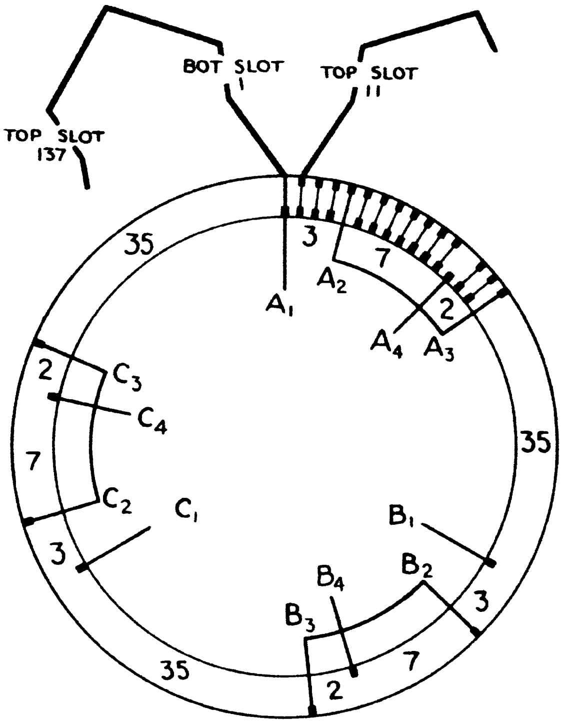


Fig. 6-46. Working diagram of a retrogressive (SP) connection for 147 slots, 14 poles, and spp = 3 1/2.

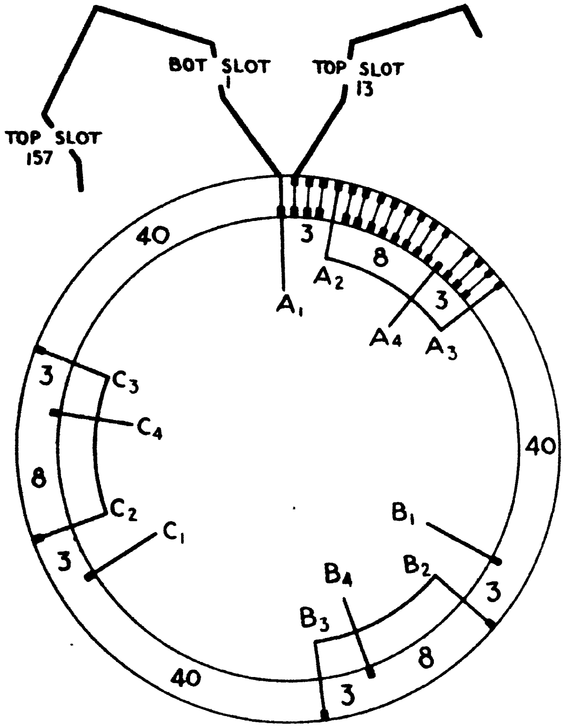


Fig. 6-47. Working diagram of a retrogressive (SP) connection for 168 slots, 14 poles, and spp = 4.

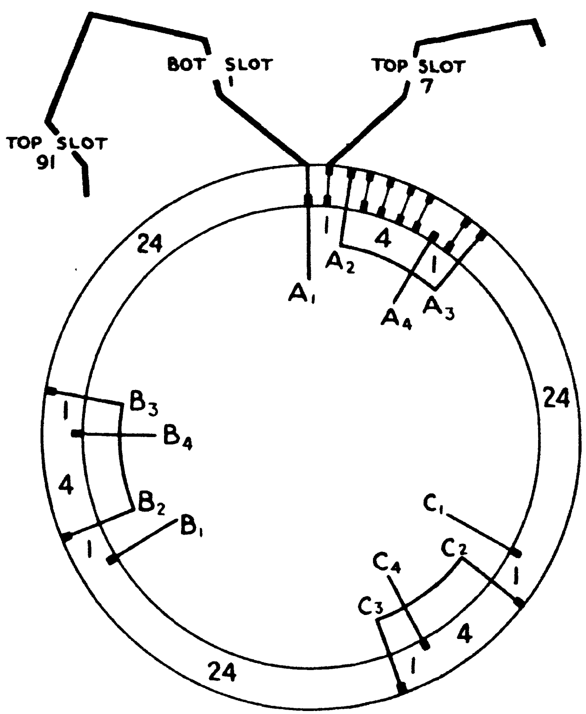


Fig. 6-48. Working diagram of a retrogressive (SP) connection for 96 slots, 16 poles, and spp = 2.

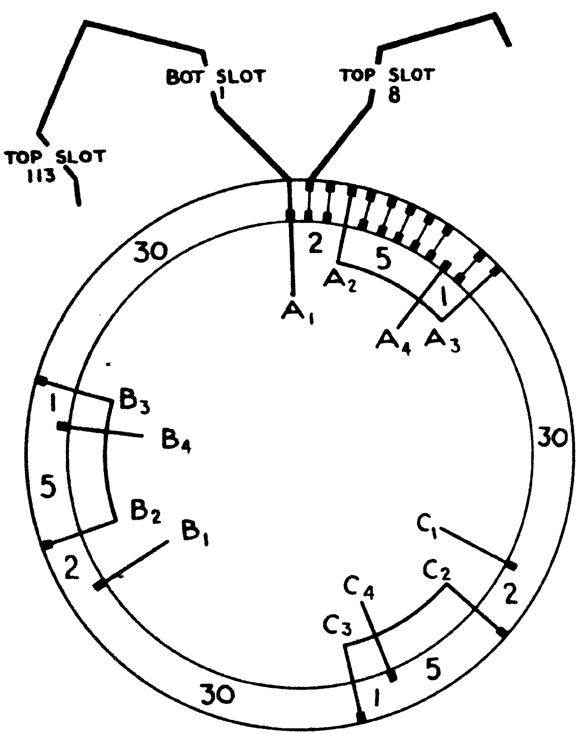


Fig. 6-49. Working diagram of a retrogressive (SP) connection for 120 slots, 16 poles, and spp = 2 1/2.

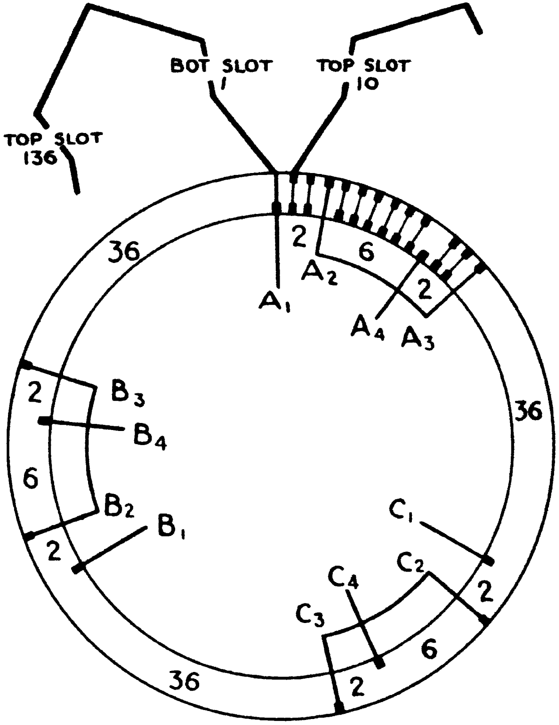


Fig. 6-50. Working diagram of a retrogressive (SP) connection for 144 slots, 16 poles, and spp = 3.

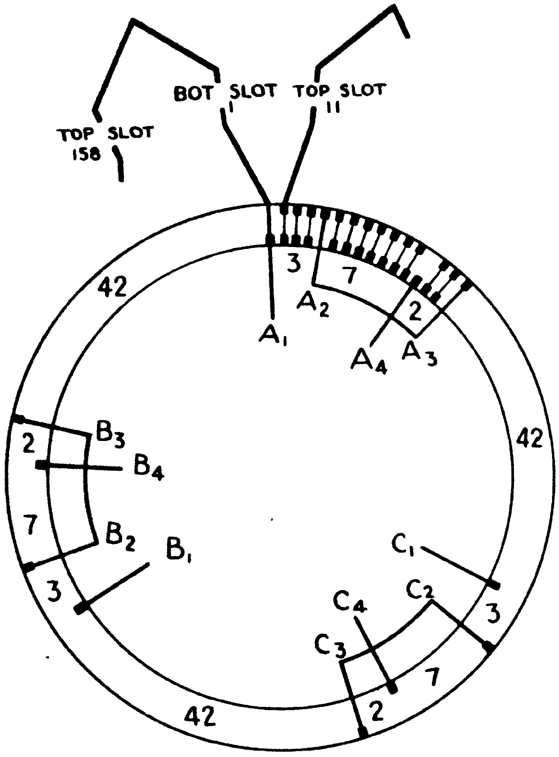


Fig. 6-51. Working diagram of a retrogressive (SP) connection for 168 slots, 16 poles, and spp = 3 1/2.

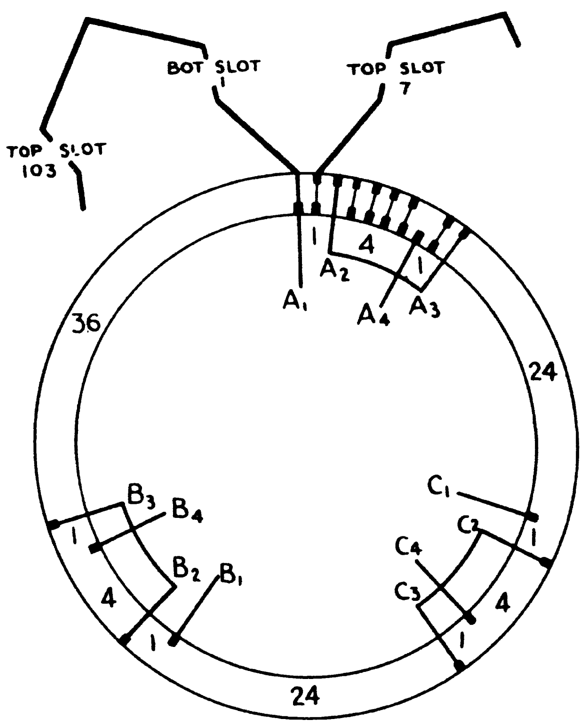


Fig. 6-52. Working diagram of a retrogressive (SP) connection for 108 slots, 18 poles, and spp = 2.

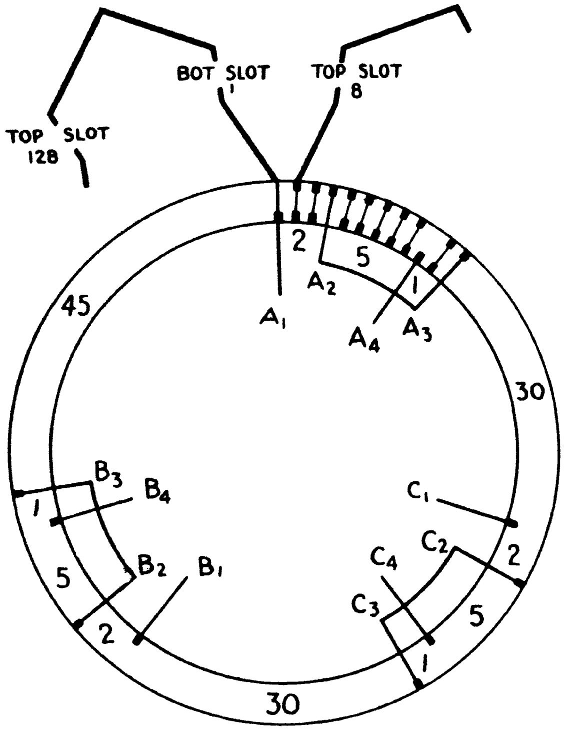


Fig. 6-53. Working diagram of a retrogressive (SP) connection for 135 slots, 18 poles, and spp = 2 1/2.

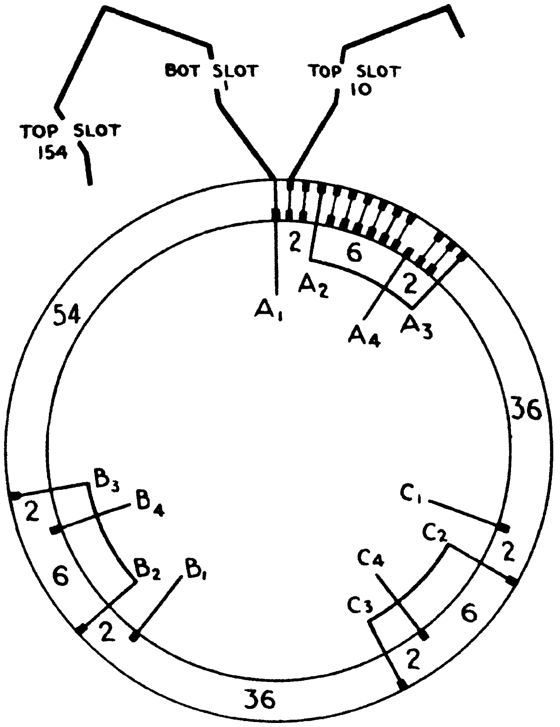


Fig. 6-54. Working diagram of a retrogressive (SP) connection for 162 slots, 18 poles, and spp = 3.

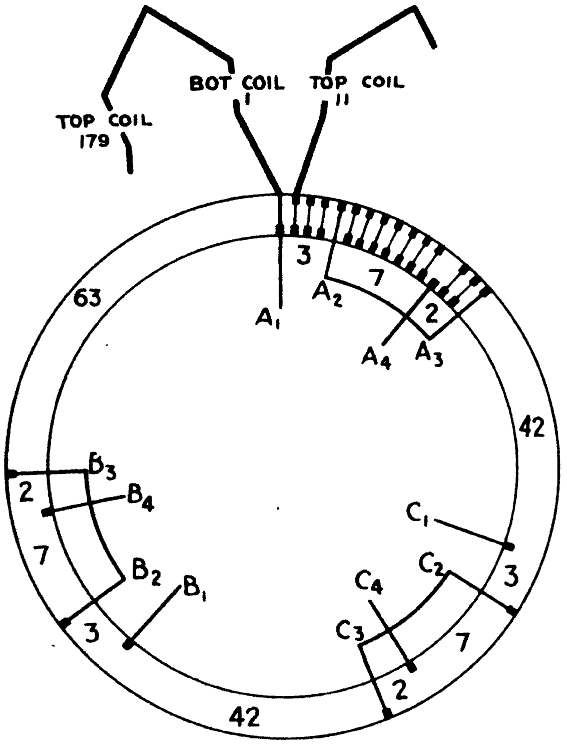


Fig. 6-55. Working diagram of a retrogressive (SP) connection for 189 slots, 18 poles, and spp = 3 1/2.

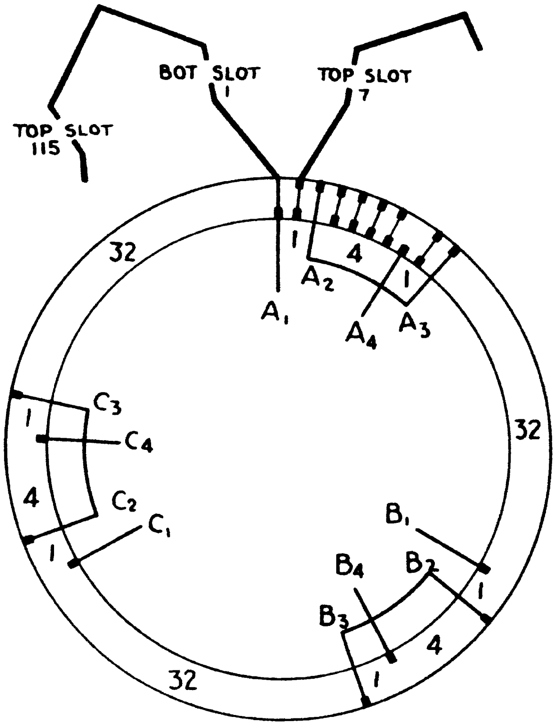


Fig. 6-56. Working diagram of a retrogressive (SP) connection for 120 slots, 20 poles, and spp = 2.

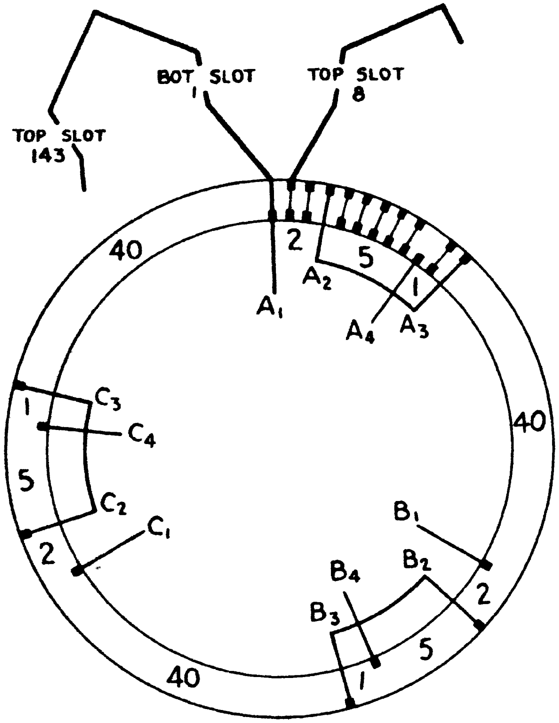


Fig. 6-57. Working diagram of a retrogressive (SP) connection for 150 slots, 20 poles, and spp = 2 1/2.

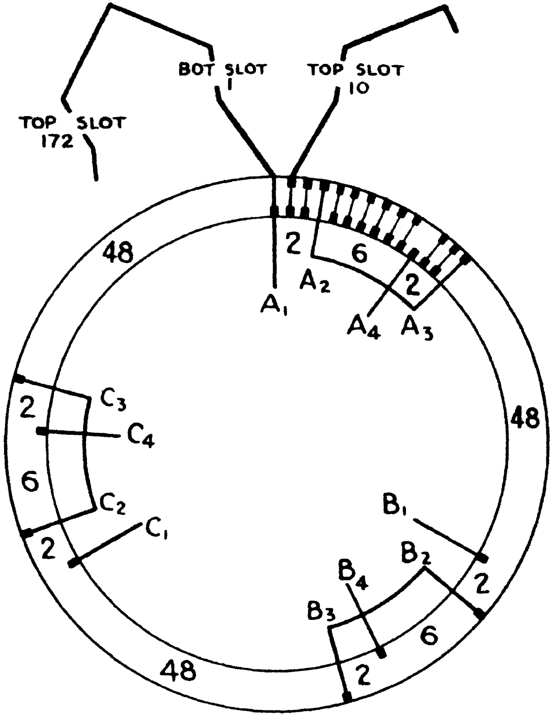


Fig. 6-58. Working diagram of a retrogressive (SP) connection for 180 slots, 20 poles, and spp = 3.

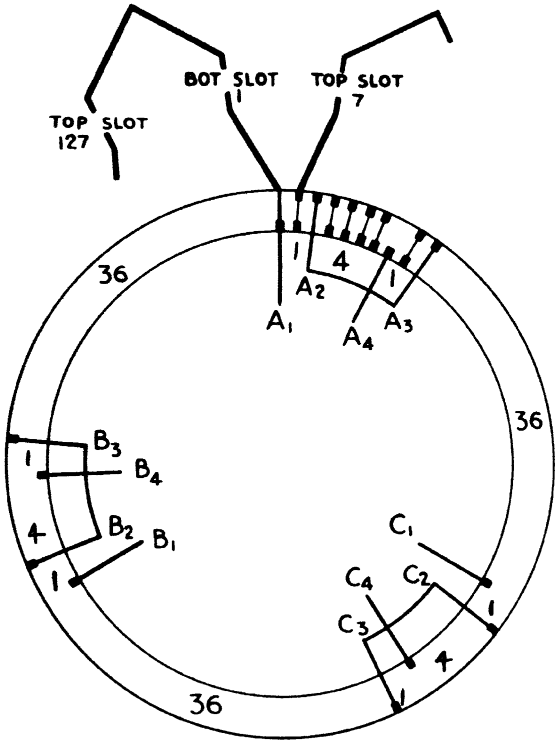


Fig. 6-59. Working diagram of a retrogressive (SP) connection for 132 slots, 22 poles, and spp = 2.

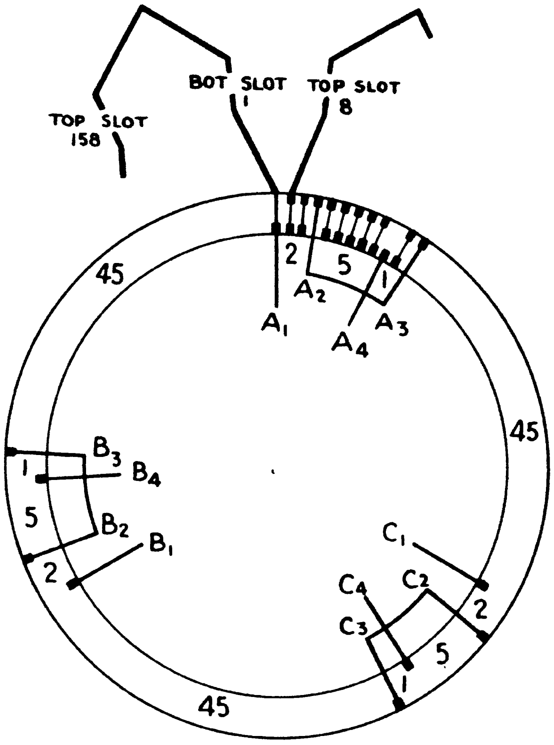


Fig. 6-60. Working diagram of a retrogressive (SP) connection for 165 slots, 22 poles, and spp = 2 1/2.

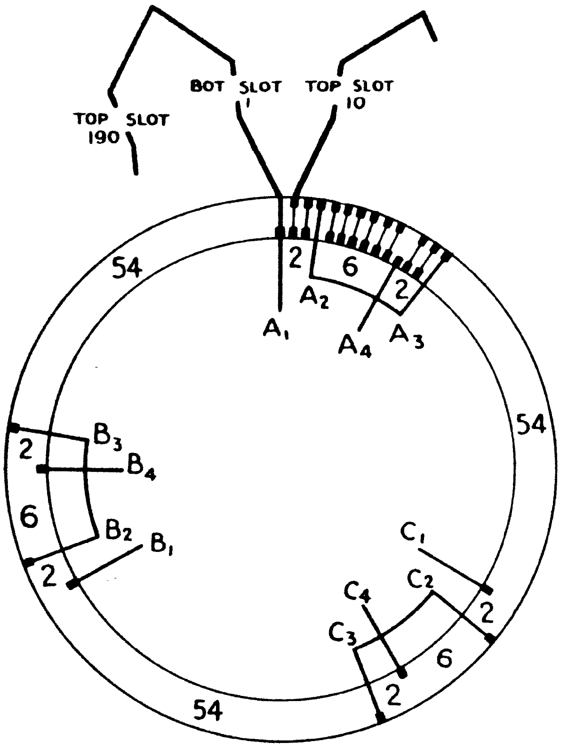


Fig. 6-61. Working diagram of a retrogressive (SP) connection for 198 slots, 22 poles, and spp = 3.

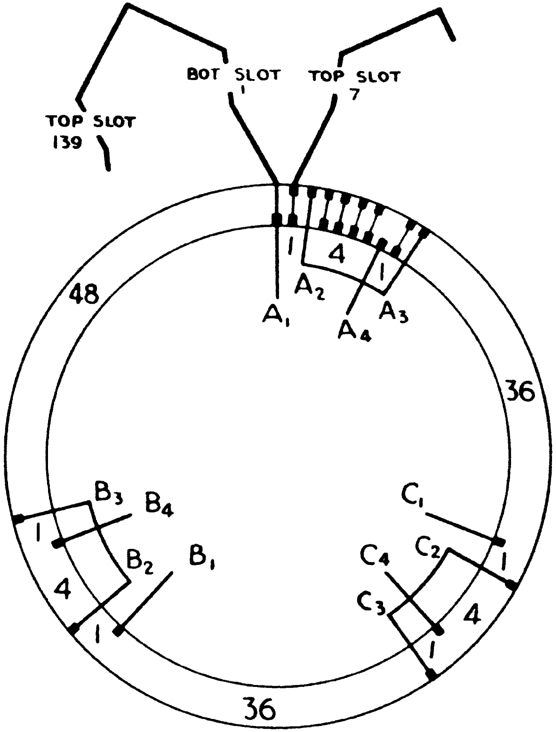


Fig. 6-62. Working diagram of a retrogressive (SP) connection for 144 slots, 24 poles, and spp = 2.

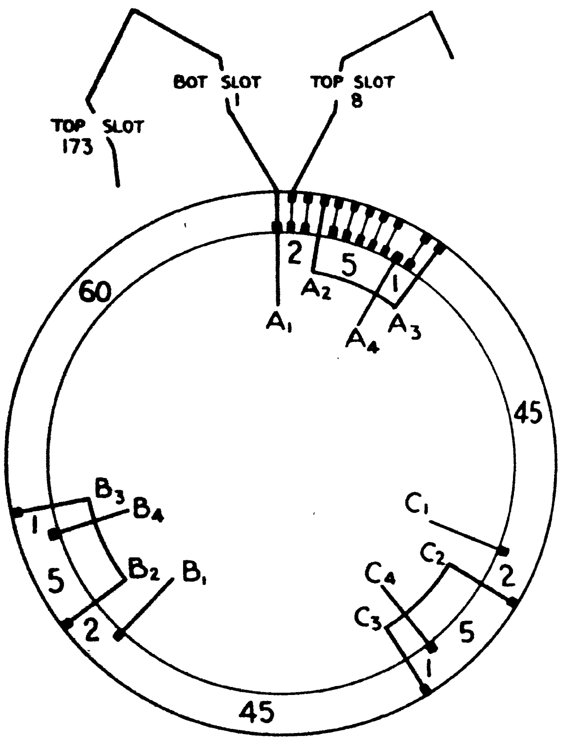


Fig. 6-63. **Working diagram of a retrogressive (SP) connection for 180 slots, 24 poles, and spp = 2 1/2.**

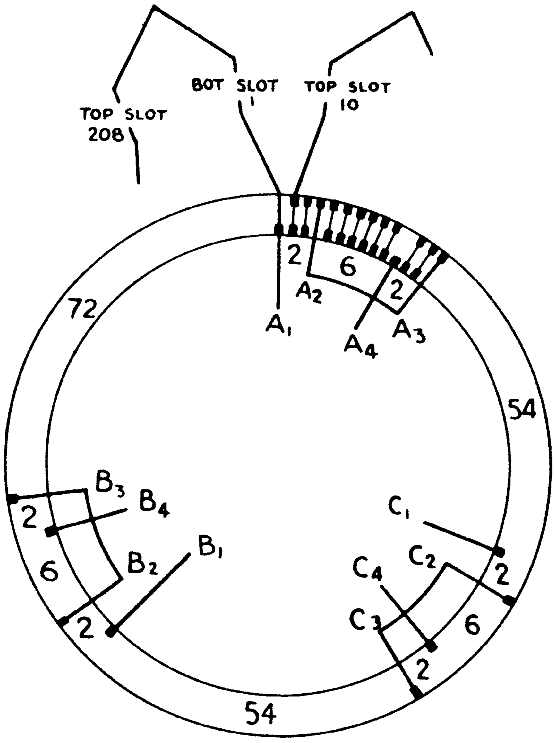


Fig. 6-64. **Working diagram of a retrogressive (SP) connection for 216 slots, 24 poles, and spp = 3.**

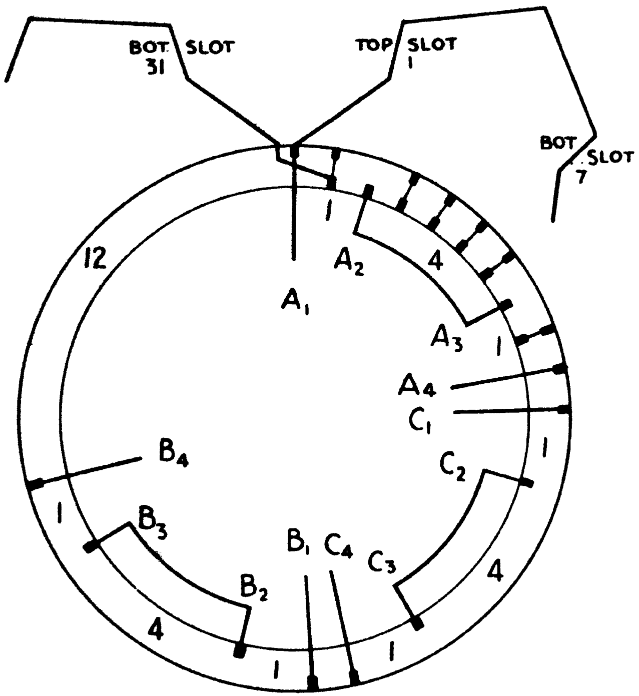


Fig. 6-65. Working diagram of a progressive-retrogressive (LP-SP) connection for 36 slots, 6 poles, and spp = 2.

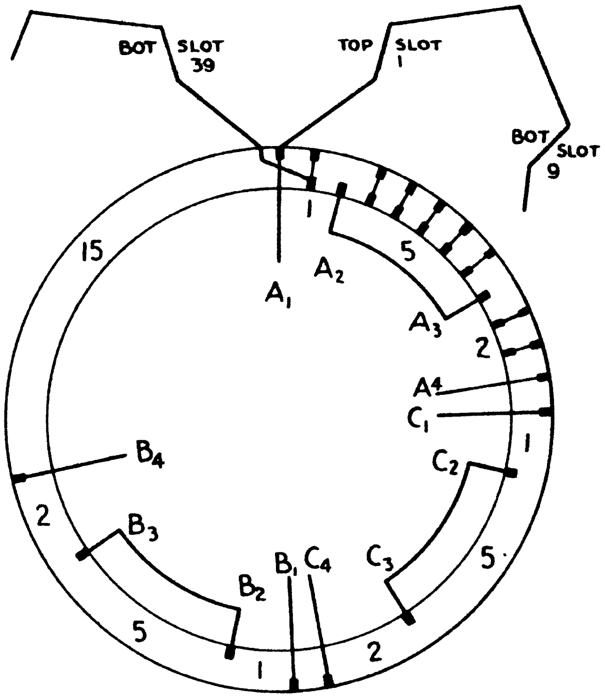


Fig. 6-66. Working diagram of a progressive-retrogressive (LP-SP) connection for 45 slots, 6 poles, and spp = 2 1/2.

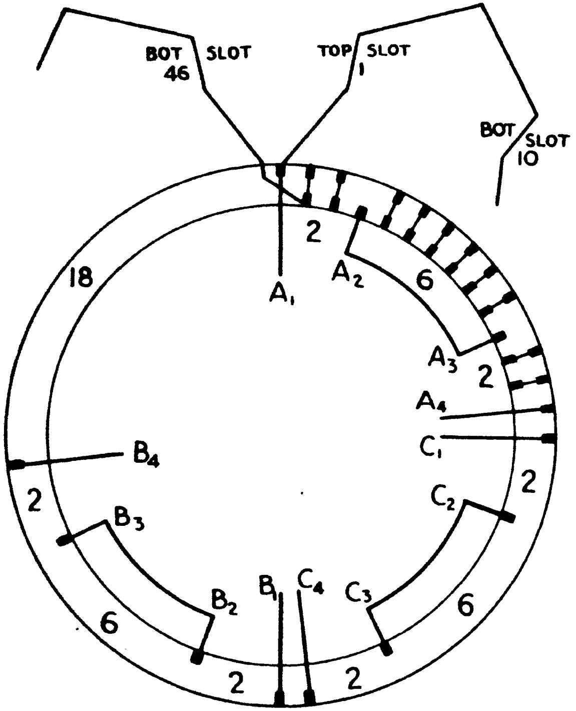


Fig. 6-67. Working diagram of a progressive-retrogressive (LP-SP) connection for 54 slots, 6 poles, and spp = 3.

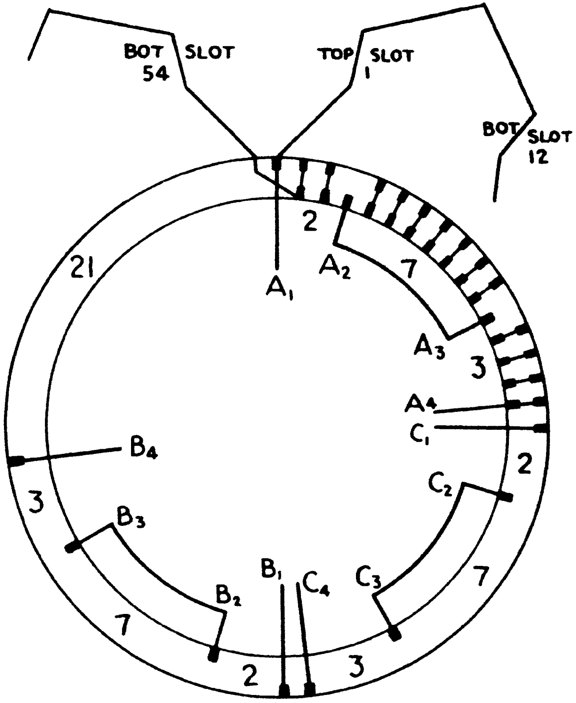


Fig. 6-68. Working diagram of a progressive-retrogressive (LP-SP) connection for 63 slots, 6 poles, and spp = 3 1/2.

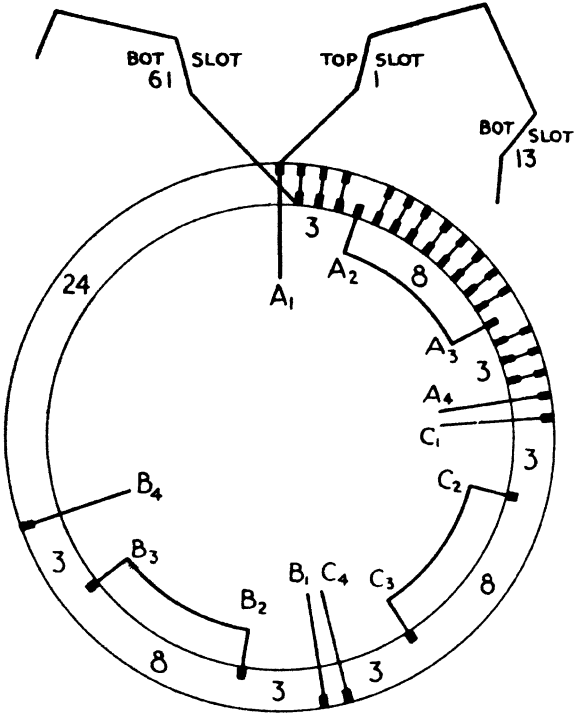


Fig. 6-69. Working diagram of a progressive-retrogressive (LP-SP) connection for 72 slots, 6 poles, and spp = 4.

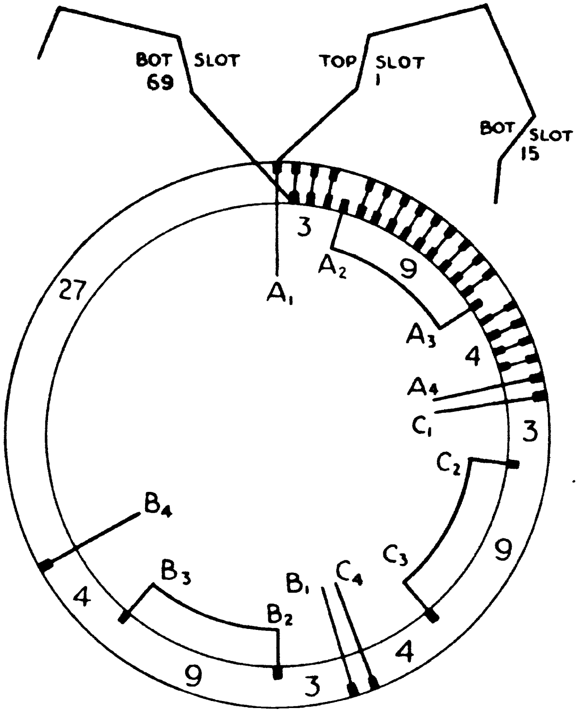


Fig. 6-70. Working diagram of a progressive-retrogressive (LP-SP) connection for 81 slots, 6 poles, and spp = 4 1/2.

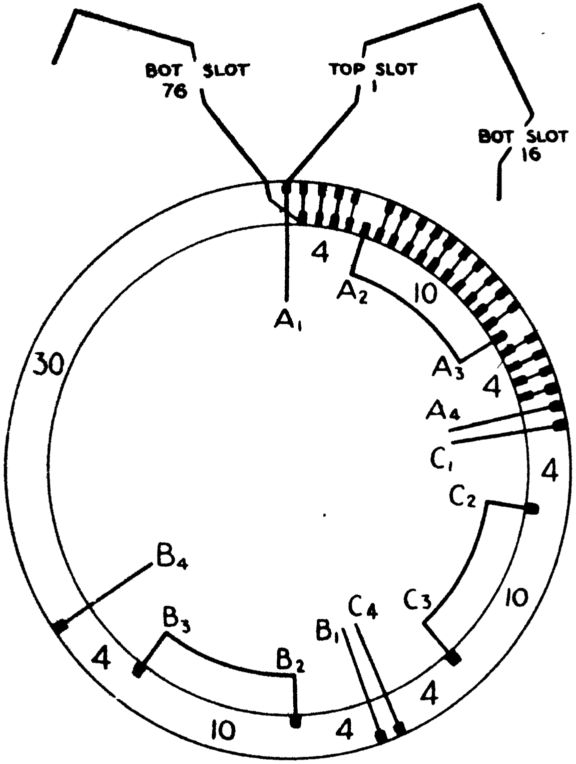


Fig. 6-71. Working diagram of a progressive-retrogressive (LP-SP) connection for 90 slots, 6 poles, and spp = 5.

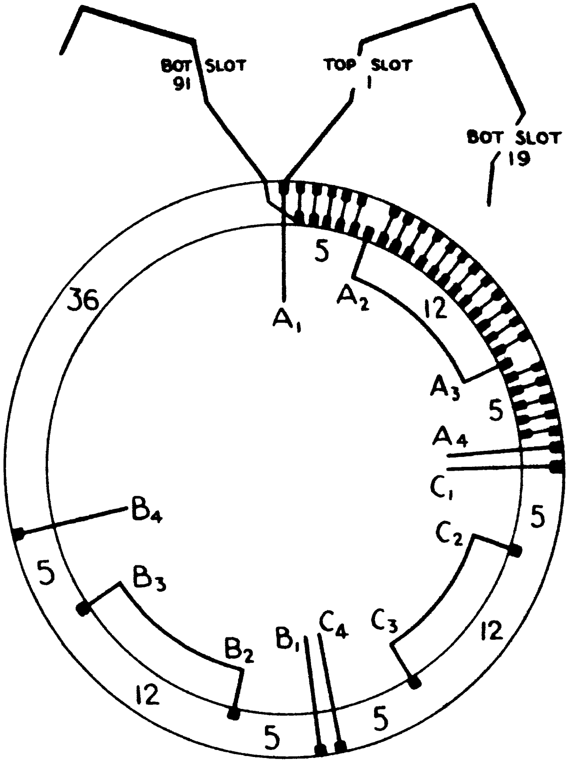


Fig. 6-72. Working diagram of a progressive-retrogressive (LP-SP) connection for 108 slots, 6 poles, and spp = 6.

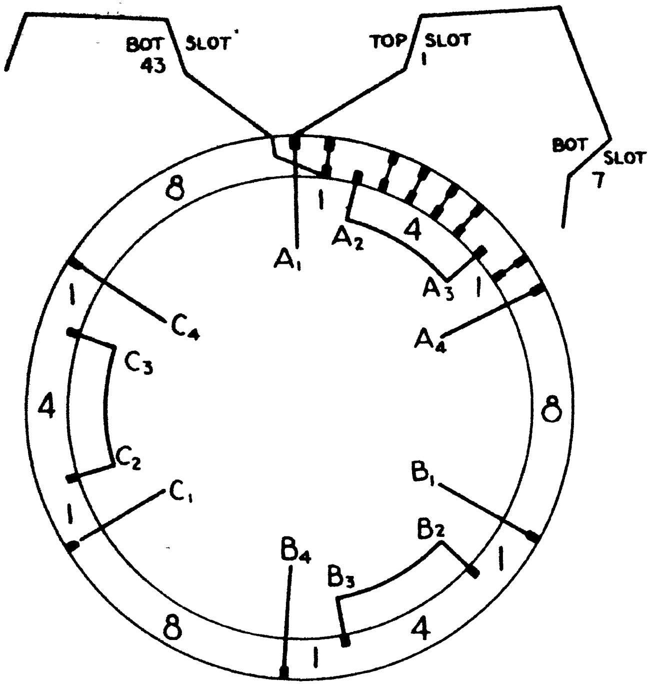


Fig. 6-73. Working diagram of a progressive-retrogressive (LP-SP) connection for 48 slots, 8 poles, and spp = 2.

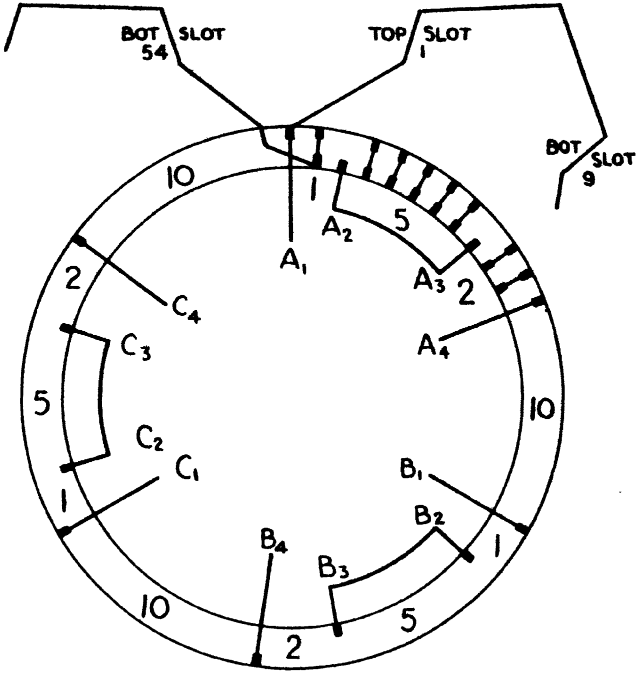


Fig. 6-74. Working diagram of a progressive-retrogressive (LP-SP) connection for 60 slots, 8 poles, and spp = 2 1/2.

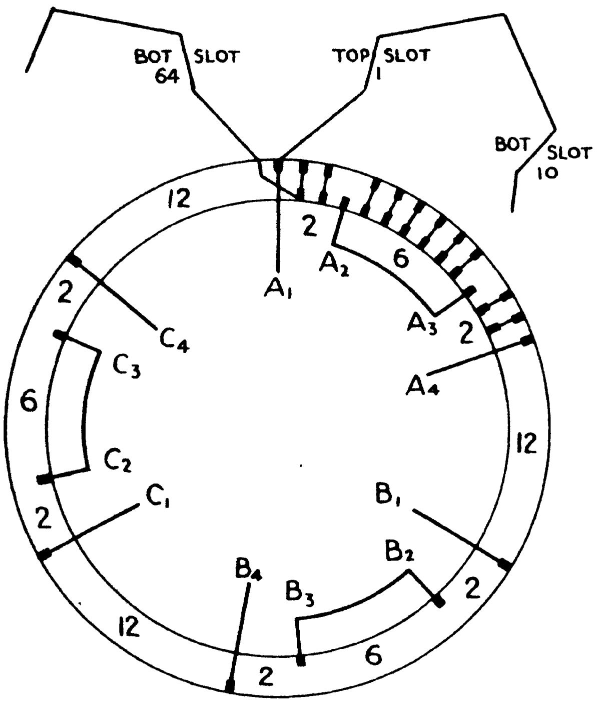


Fig. 6-75. Working diagram of a progressive-retrogressive (LP-SP) connection for 72 slots, 8 poles, and spp = 3.

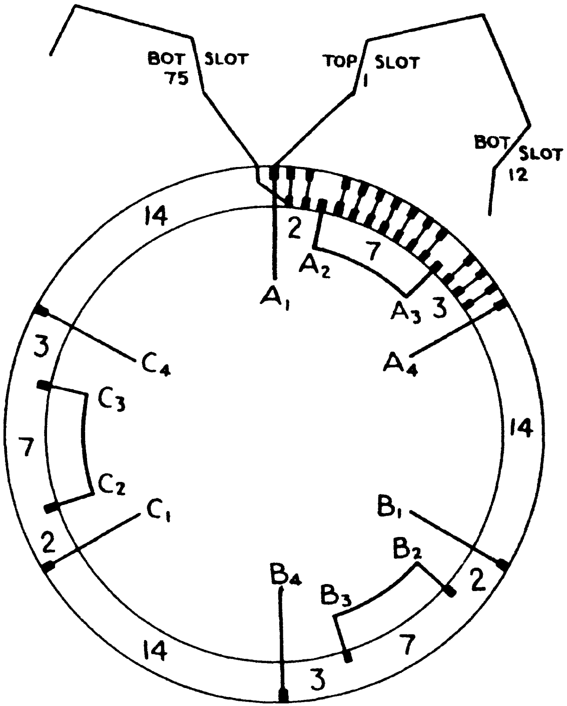


Fig. 6-76. Working diagram of a progressive-retrogressive (LP-SP) connection for 84 slots, 8 poles, and spp = 3 1/2.

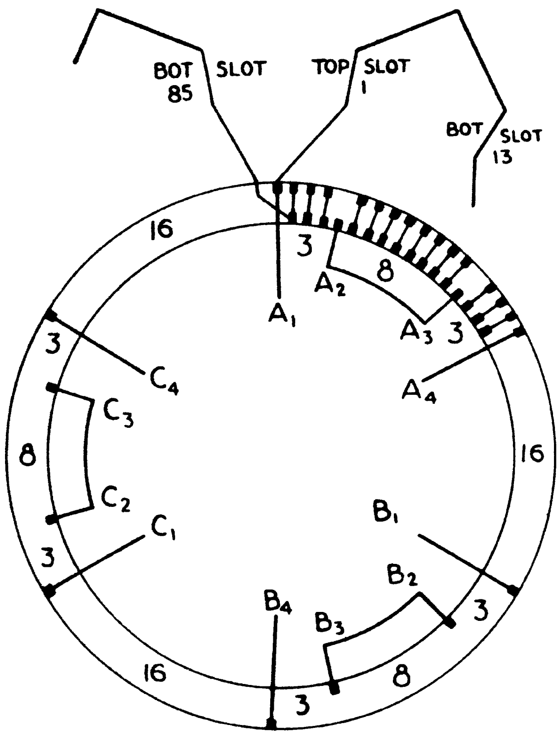


Fig. 6-77. Working diagram of a progressive-retrogressive (LP-SP) connection for 96 slots, 8 poles, and spp = 4.

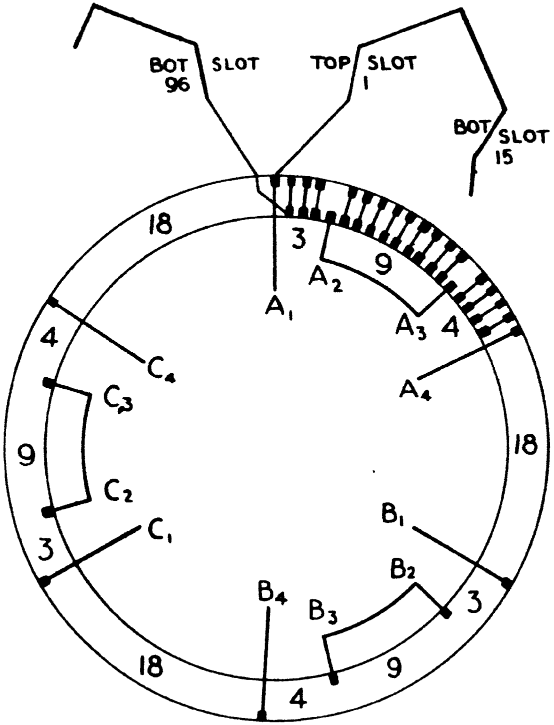


Fig. 6-78. Working diagram of a progressive-retrogressive (LP-SP) connection for 108 slots, 8 poles, and spp = 4 1/2.

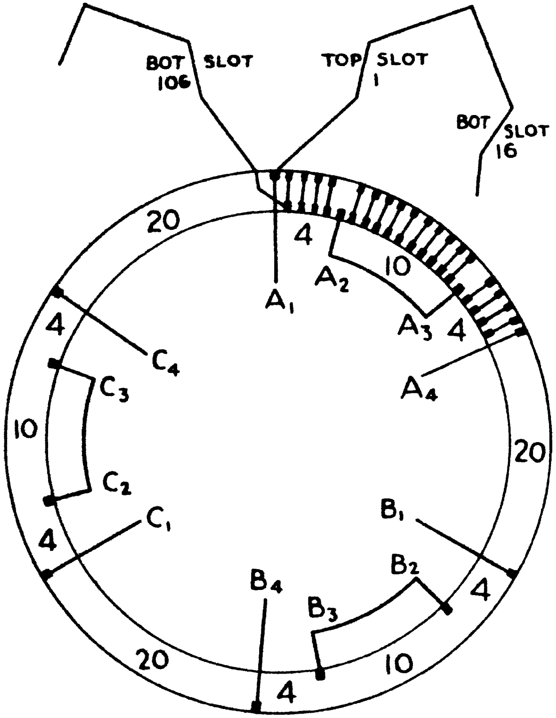


Fig. 6-79. Working diagram of a progressive-retrogressive (LP-SP) connection for 120 slots, 8 poles, and spp = 5.

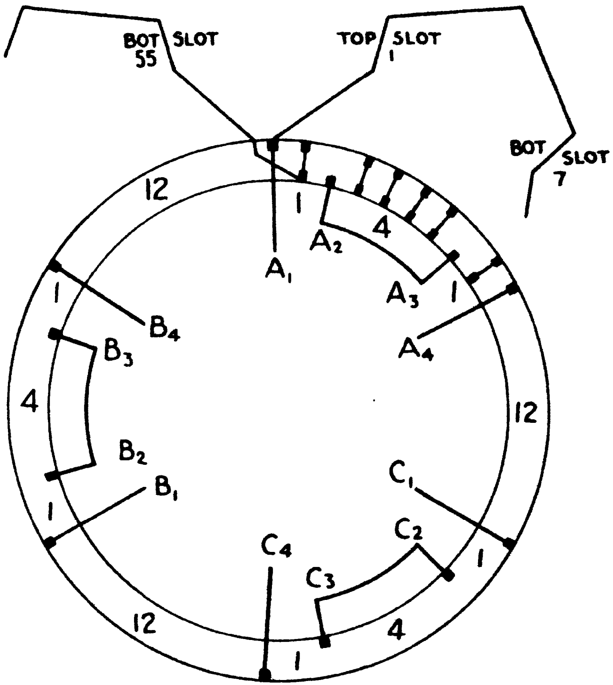


Fig. 6-80. Working diagram of a progressive-retrogressive (LP-SP) connection for 60 slots, 10 poles, and spp = 2.

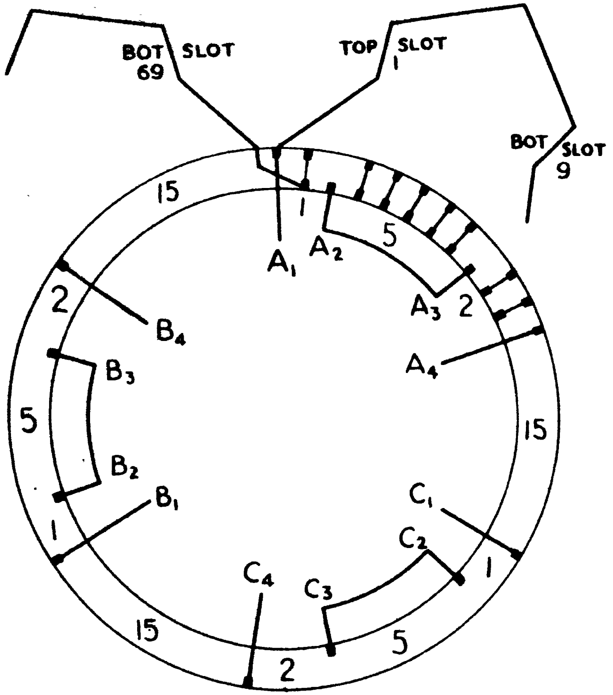


Fig. 6-81. Working diagram of a progressive-retrogressive (LP-SP) connection for 75 slots, 10 poles, and spp = 2 1/2.

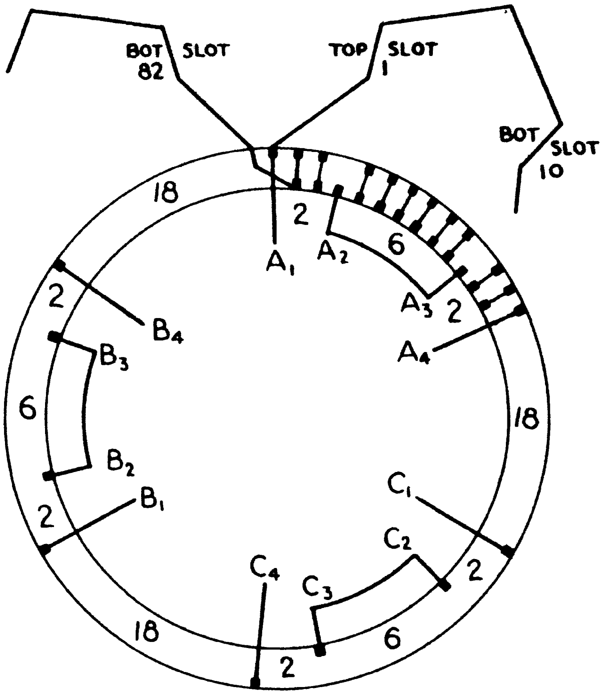


Fig. 6-82. Working diagram of a progressive-retrogressive (LP-SP) connection for 90 slots, 10 poles, and spp = 3.

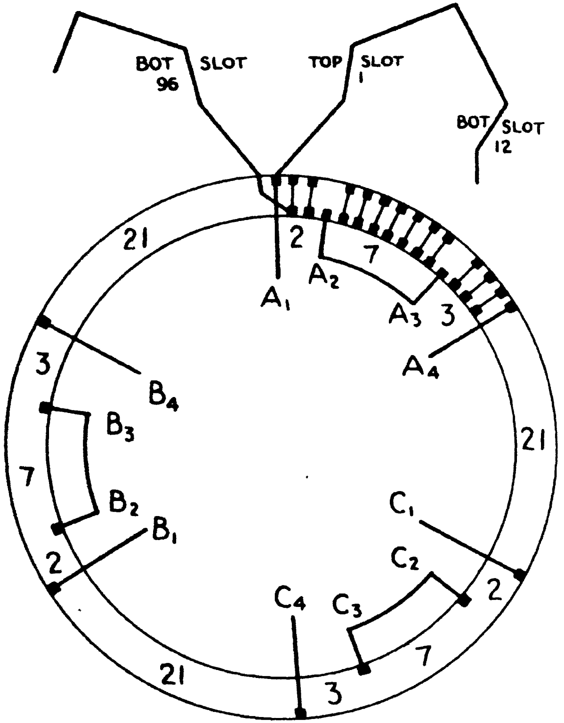


Fig. 6-83. Working diagram of a progressive-retrogressive (LP-SP) connection for 105 slots, 10 poles, and spp = 3 1/2.

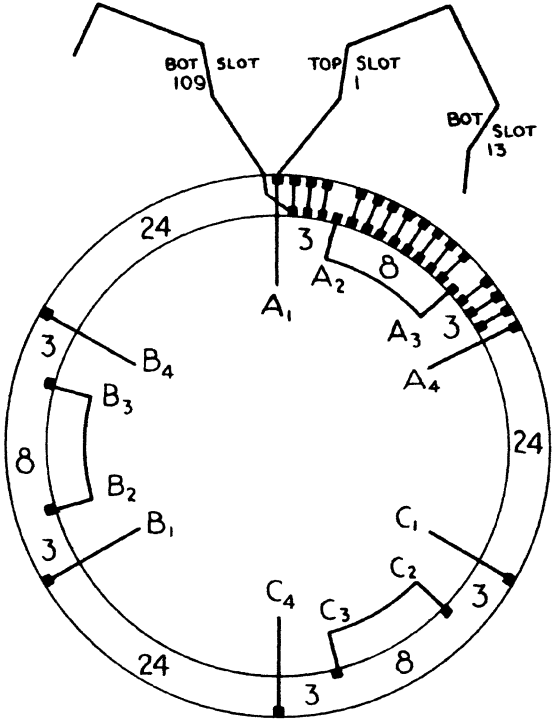


Fig. 6-84. Working diagram of a progressive-retrogressive (LP-SP) connection for 120 slots, 10 poles, and spp = 4.

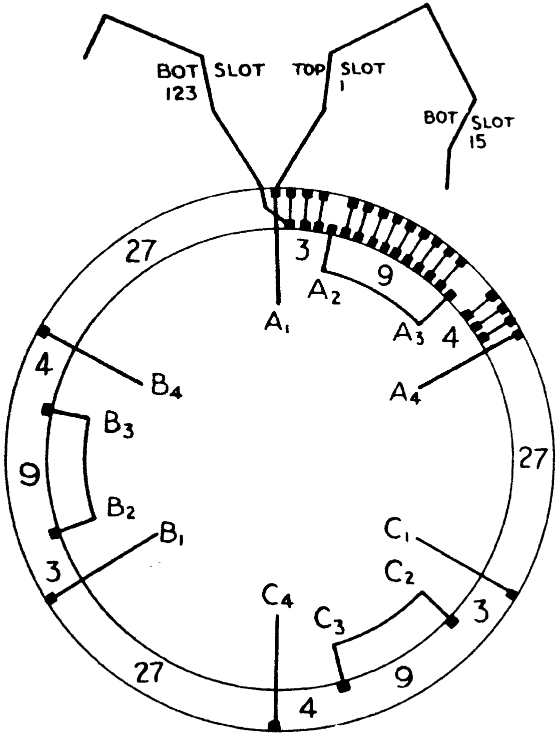


Fig. 6-85. Working diagram of a progressive-retrogressive (LP-SP) connection for 135 slots, 10 poles, and spp = 4 1/2

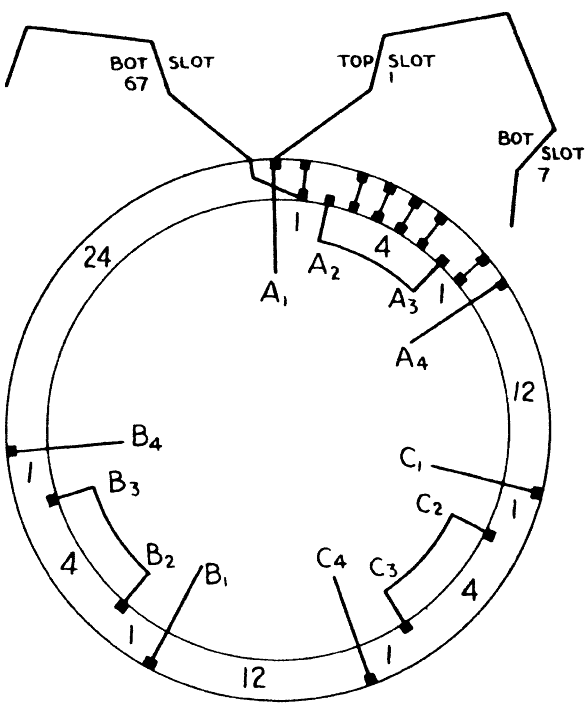


Fig. 6-86. Working diagram of a progressive-retrogressive (LP-SP) connection for 72 slots, 12 poles, and spp = 2.

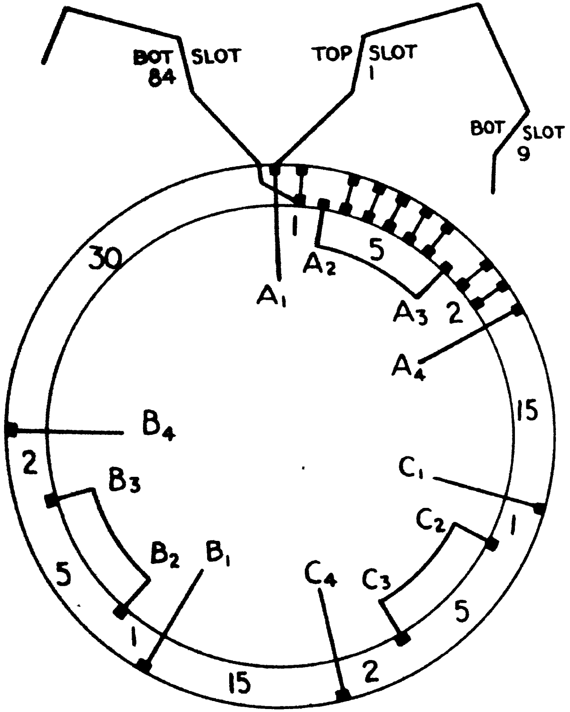


Fig. 6-87. Working diagram of a progressive-retrogressive (LP-SP) connection for 90 slots, 12 poles, and spp = 2 1/2.

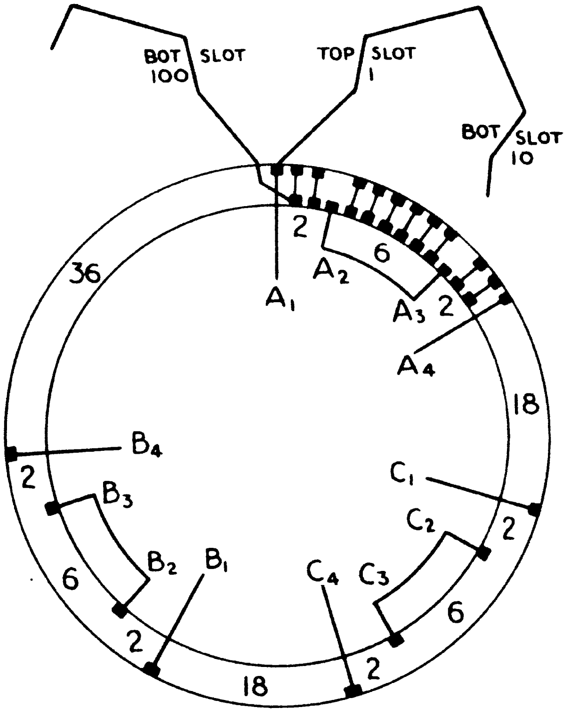


Fig. 6-88. Working diagram of a progressive-retrogressive (LP-SP) connection for 108 slots, 12 poles, and spp = 3.

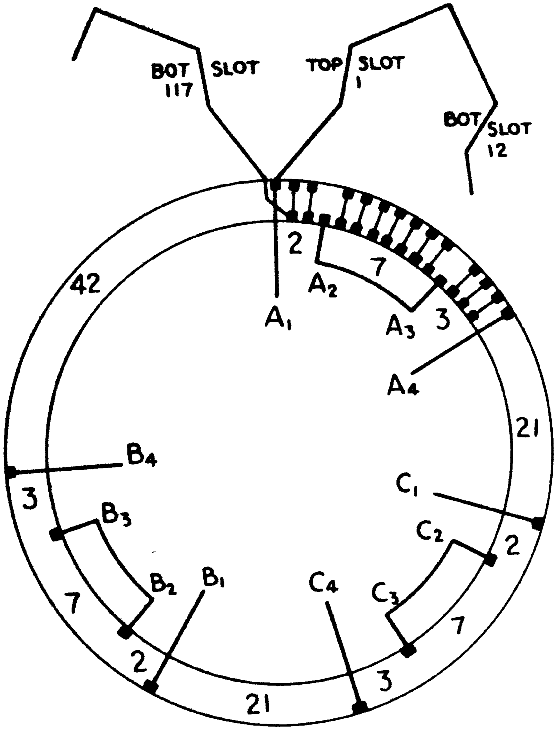


Fig. 6-89. Working diagram of a progressive-retrogressive (LP-SP) connection for 126 slots, 12 poles, and spp = 3 1/2.

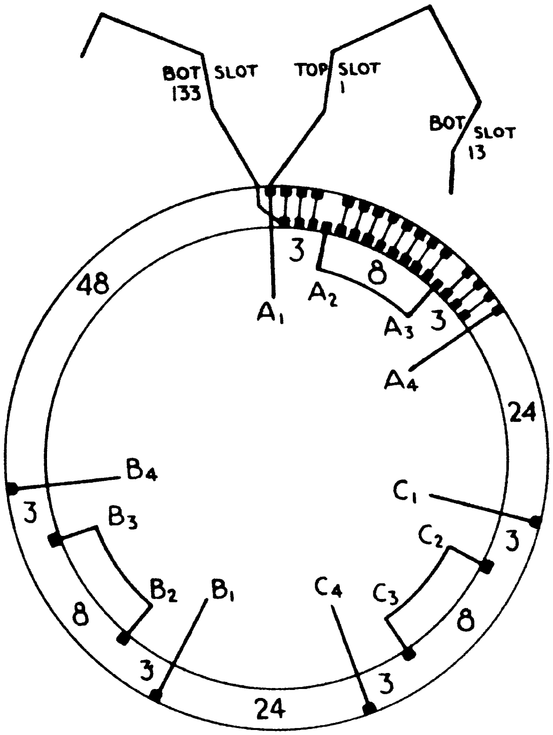


Fig. 6-90. Working diagram of a progressive-retrogressive (LP-SP) connection for 144 slots, 12 poles, and spp = 4.

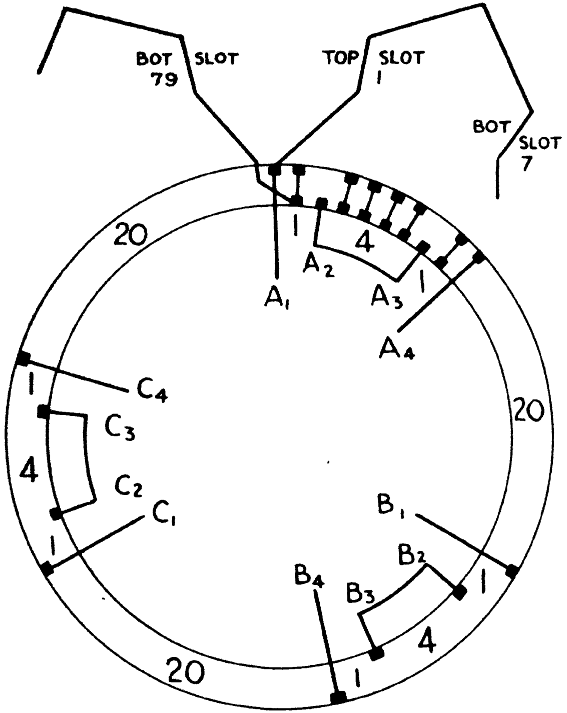


Fig. 6-91. Working diagram of a progressive-retrogressive (LP-SP) connection for 84 slots, 14 poles, and spp = 2.

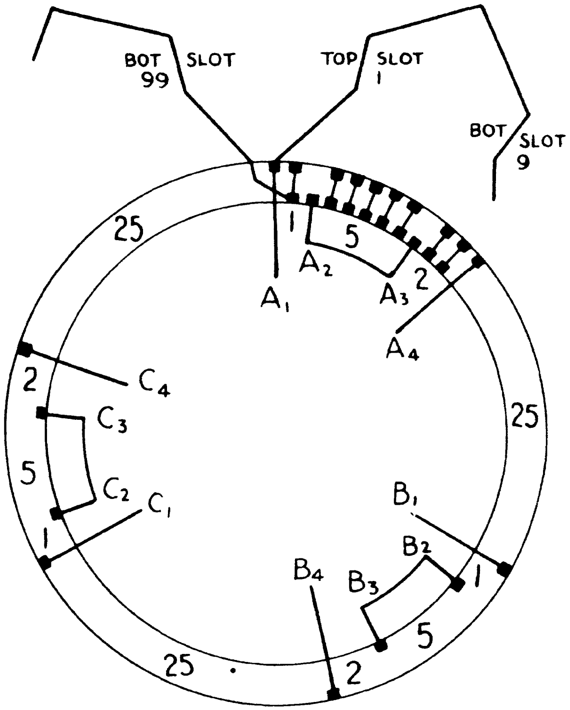


Fig. 6-92. Working diagram of a progressive-retrogressive (LP-SP) connection for 105 slots, 14 poles, and spp = 2 1/2

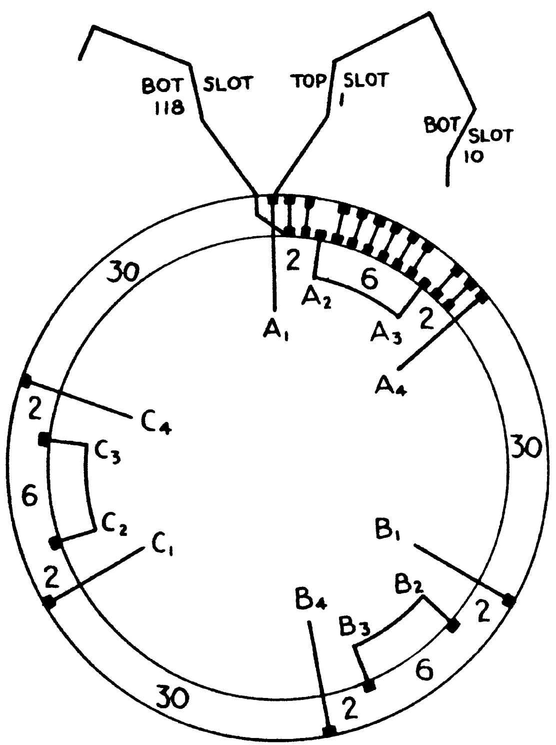


Fig. 6-93. Working diagram of a progressive-retrogressive (LP-SP) connection for 126 slots, 14 poles, and spp = 3.

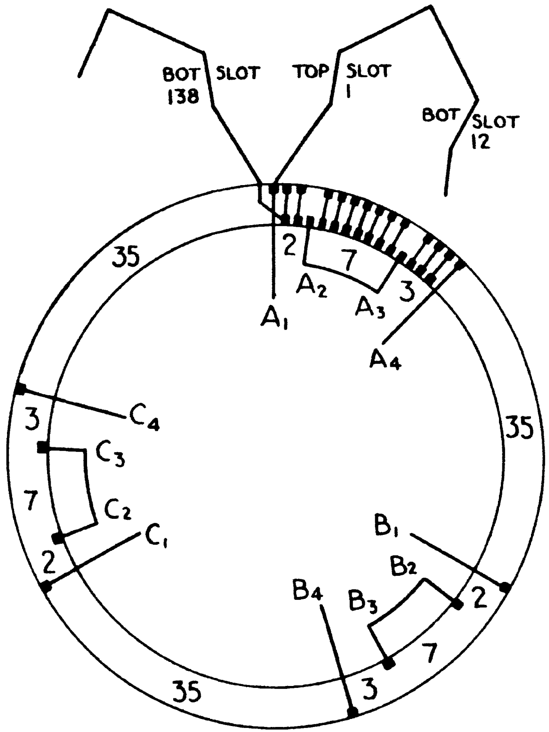


Fig. 6-94. Working diagram of a progressive-retrogressive (LP-SP) connection for 147 slots, 14 poles, and spp = 3 1/2

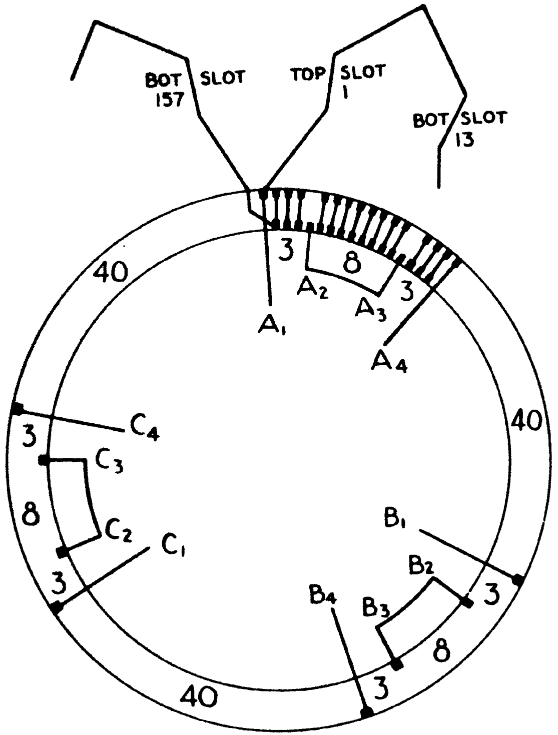


Fig. 6-95. Working diagram of a progressive-retrogressive (LP-SP) connection for 168 slots, 14 poles, and spp = 4.

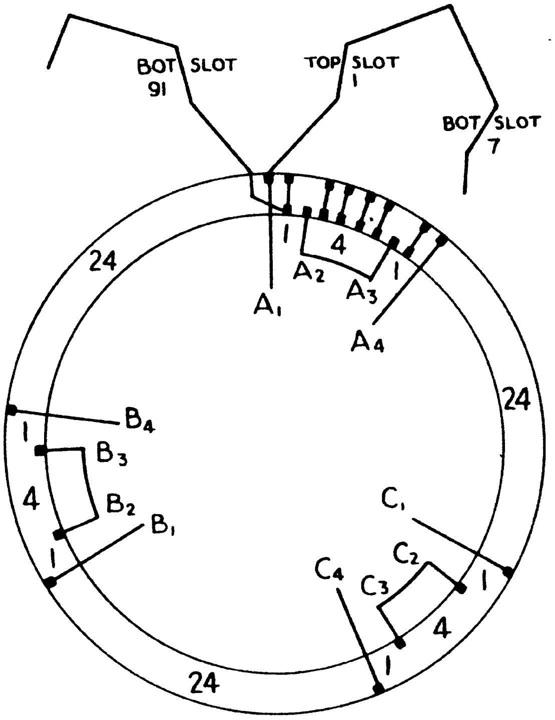


Fig. 6-96. Working diagram of a progressive-retrogressive (LP-SP) connection for 96 slots, 16 poles, and spp = 2.

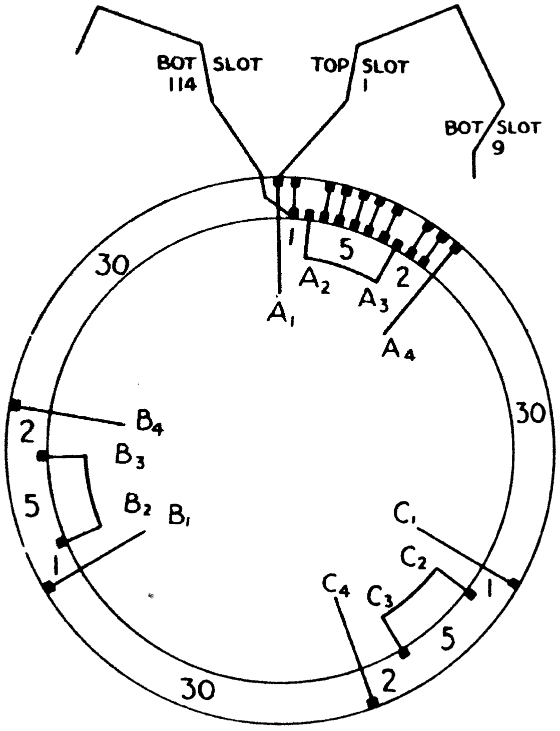


Fig. 6-97. Working diagram of a progressive-retrogressive (LP-SP) connection for 120 slots, 16 poles, and spp = 2 1/2

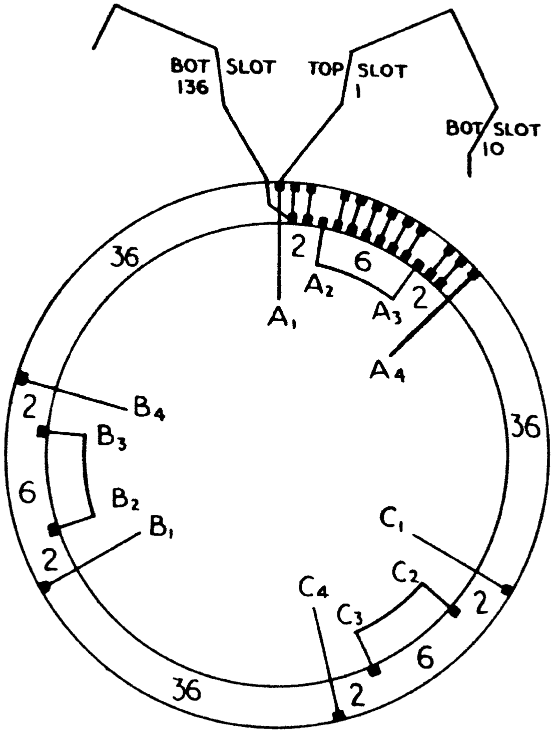


Fig. 6-98. Working diagram of a progressive-retrogressive (LP-SP) connection for 144 slots, 16 poles, and spp = 3.

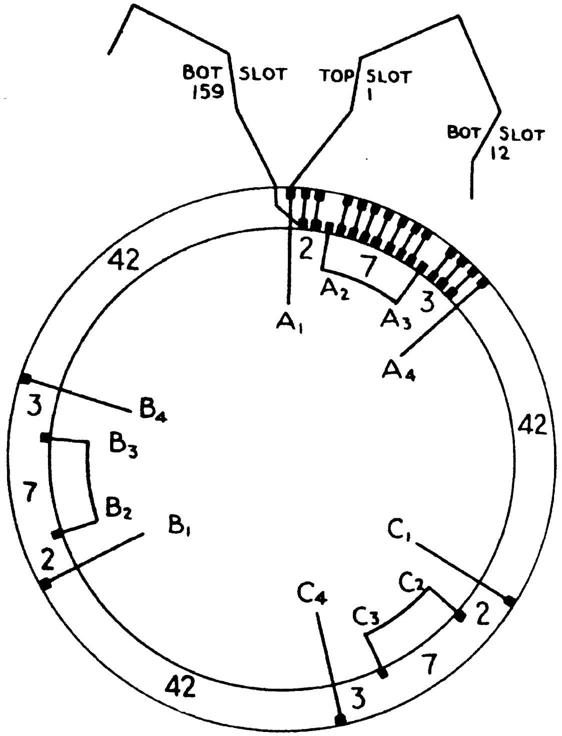


Fig. 6-99. Working diagram of a progressive-retrogressive (LP-SP) connection for 168 slots, 16 poles, and spp = 3 1/2.

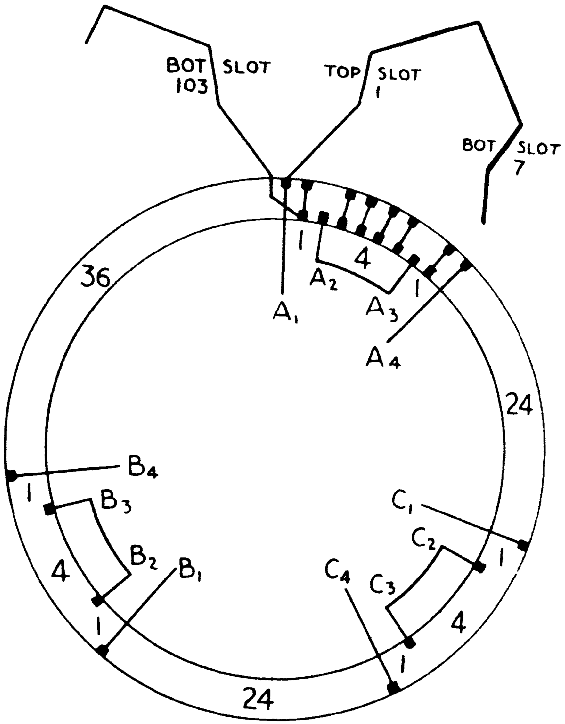


Fig.6-100. Working diagram of a progressive-retrogressive (LP-SP) connection for 108 slots, 18 poles, and spp = 2.

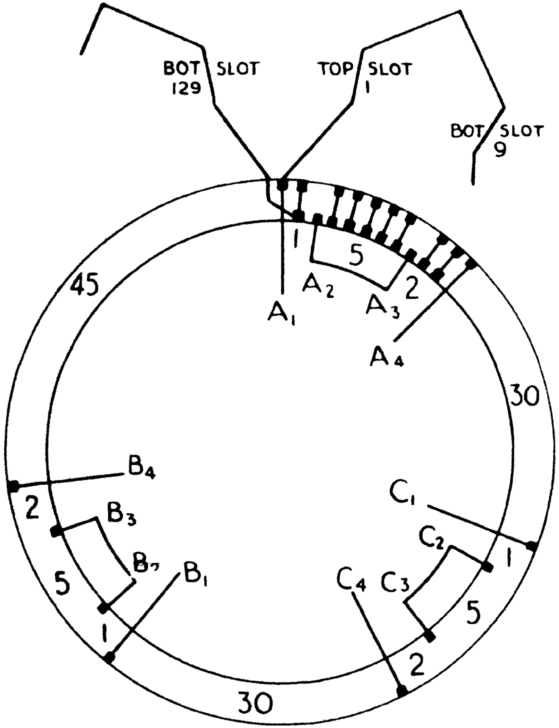


Fig.6-101. Working diagram of a progressive-retrogressive (LP-SP) connection for 135 slots, 18 poles, and spp = 2 1/2

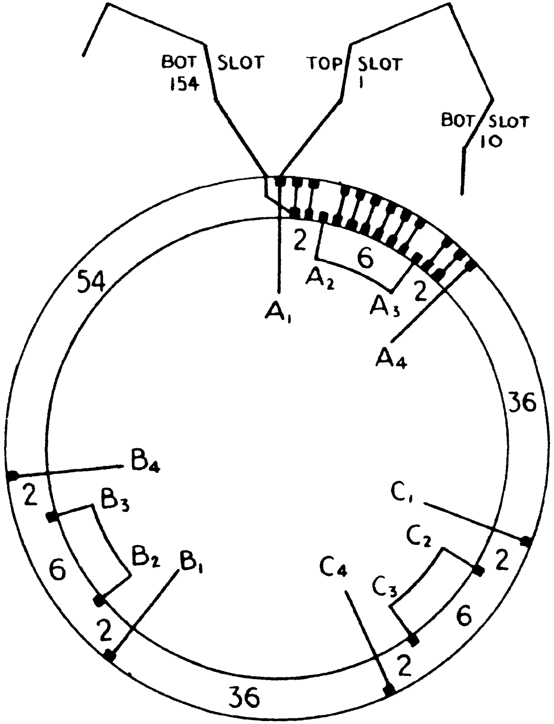


Fig.6-102. Working diagram of a progressive-retrogressive (LP-SP) connection for 162 slots, 18 poles, and spp = 3.

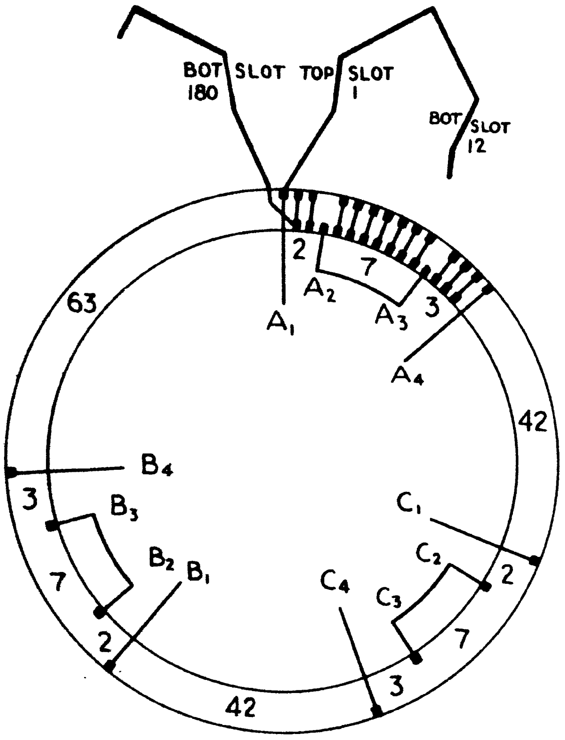


Fig.6-103. Working diagram of a progressive-retrogressive (LP-SP) connection for 189 slots, 18 poles, and spp = 3 1/2

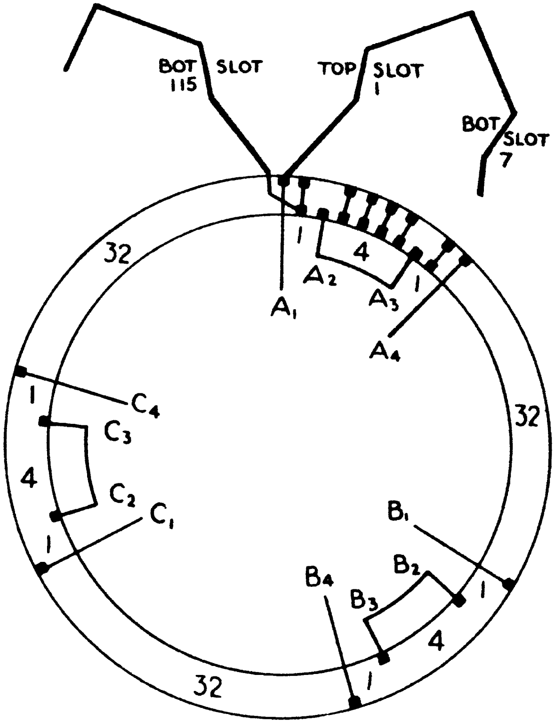


Fig.6-104. Working diagram of a progressive-retrogressive (LP-SP) connection for 120 slots, 20 poles, and spp = 2.

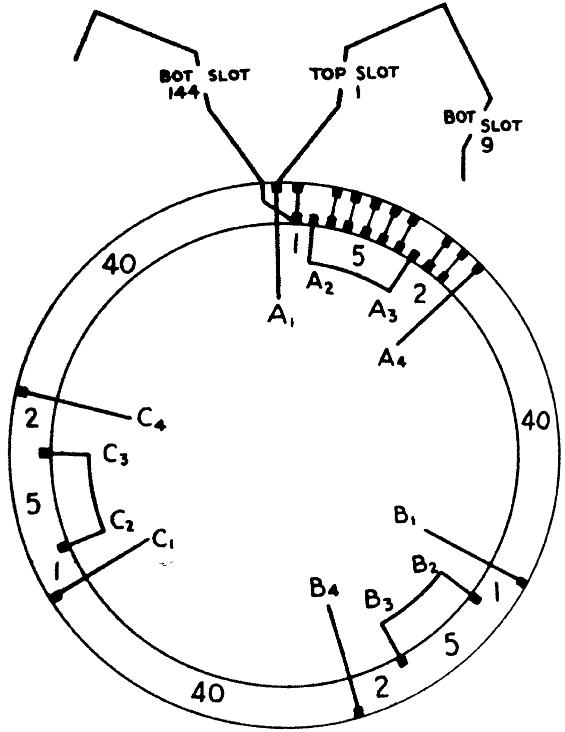


Fig.6-105. Working diagram of a progressive-retrogressive (LP-SP) connection for 150 slots, 20 poles, and spp = 2 1/2

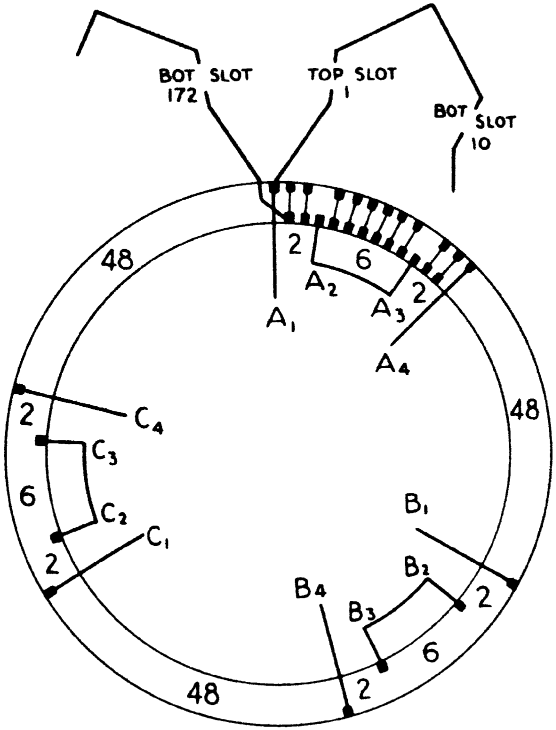


Fig.6-106. Working diagram of a progressive-retrogressive (LP-SP) connection for 180 slots, 20 poles, and spp = 3.

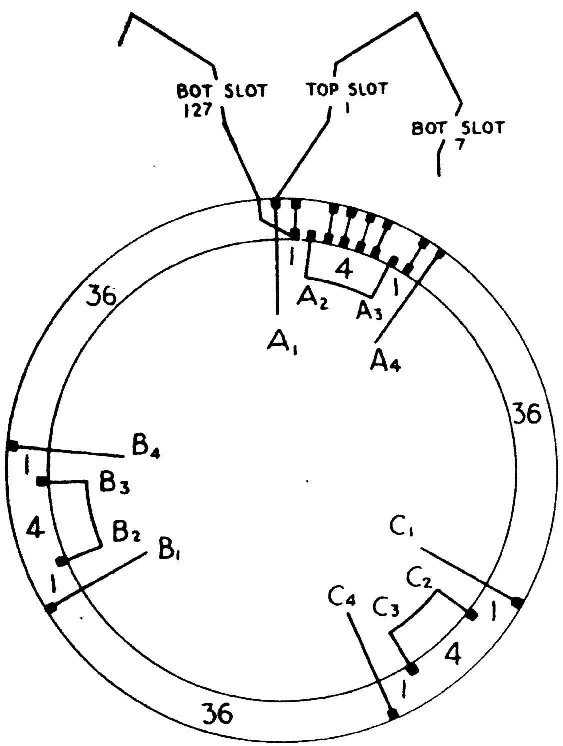


Fig.6-107. Working diagram of a progressive-retrogressive (LP-SP) connection for 132 slots, 22 poles, and spp = 2.

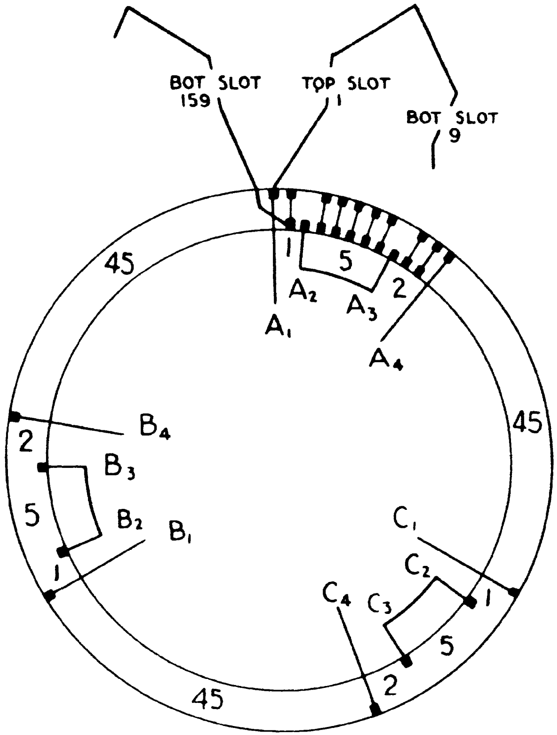


Fig.6-108. Working diagram of a progressive-retrogressive (LP-SP) connection for 165 slots, 22 poles, and spp = 2 1/2

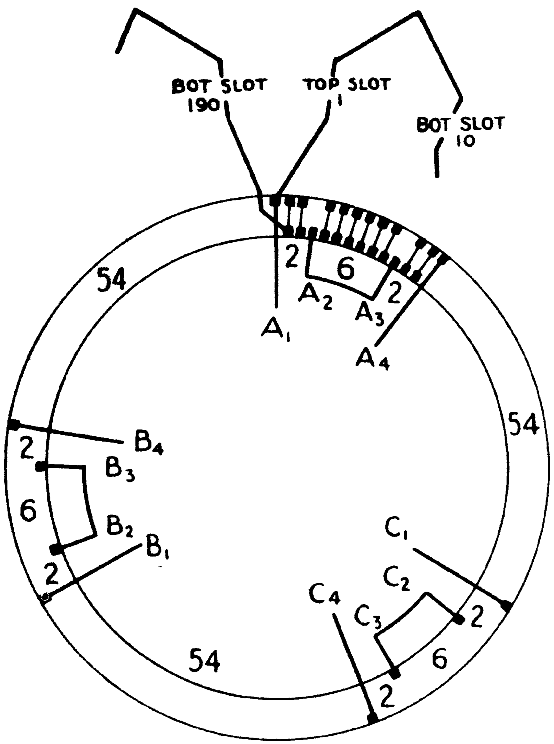


Fig.6-109. Working diagram of a progressive-retrogressive (LP-SP) connection for 198 slots, 22 poles, and spp = 3.

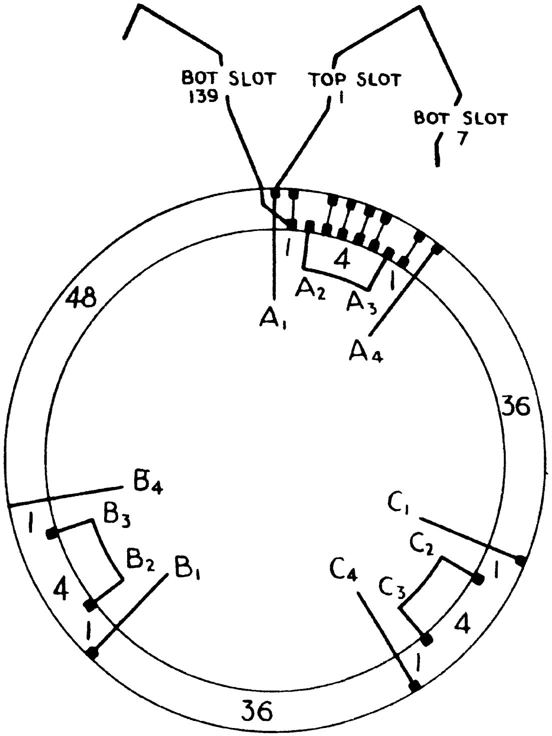


Fig.6-110. Working diagram of a progressive-retrogressive (LP-SP) connection for 144 slots, 24 poles, and spp = 2.

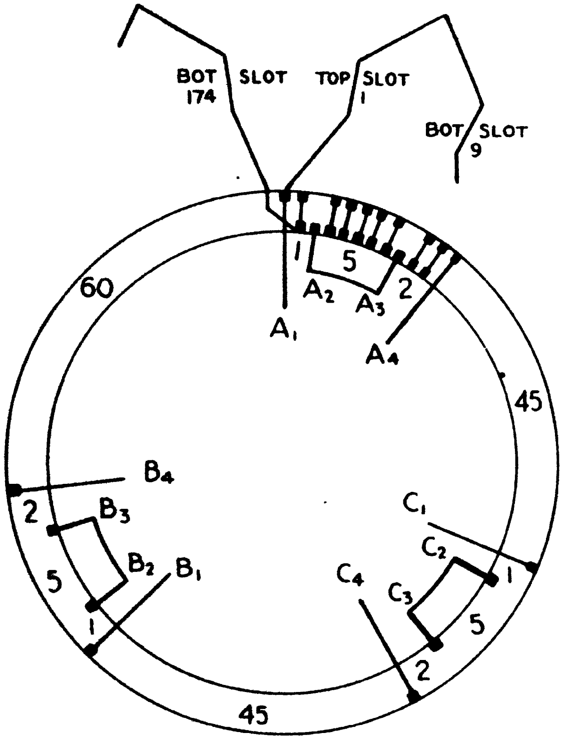


Fig.6-111. Working diagram of a progressive-retrogressive (LP-SP) connection for 180 slots, 24 poles, and spp = 2 1/2

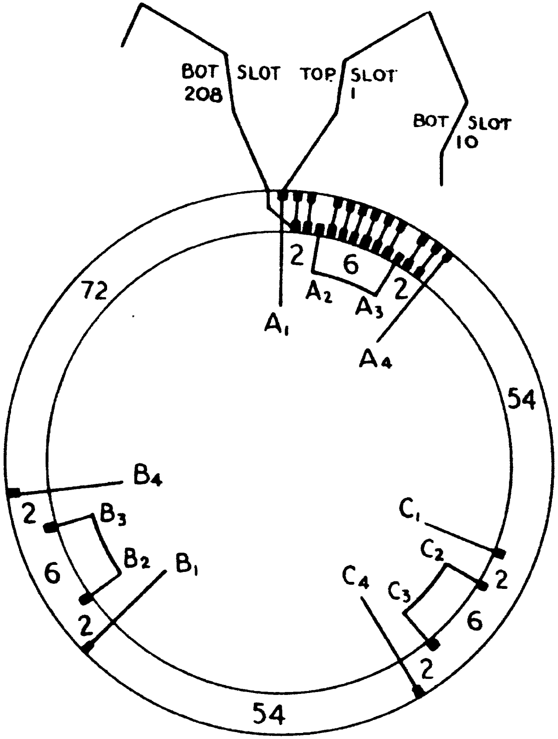


Fig.6-112. Working diagram of a progressive-retrogressive (LP-SP) connection for 216 slots, 24 poles, and spp = 3.

TABLE NO. 6-1

CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 1-1/2

Back Pitch = 5 Slot Pitches   Front Pitch = 4 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Short Front Pitch Coils Between A_1 and A_2 B_1 and B_2 C_1 and C_2	No.of Normal Front Pitch Coils Between A_2 and A_4 B_2 and B_4 C_2 and C_4	No.of Short Front Pitch Coils Between A_4 and A_3 B_4 and B_3 C_4 and C_3	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads					A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	18	1	6	6	10	13	18	18	4	7	12	12	16	1	3	0	-	-	-	0	0	0	-
6	27	1	6	6	10	13	18	18	22	7	12	12	16	1	3	0	-	-	-	0	0	3	-
8	36	1	6	6	10	13	18	18	22	25	30	30	34	1	3	0	6	6	6	-	-	-	-
10	45	1	6	6	10	31	36	36	40	16	21	21	25	1	3	0	-	-	-	9	9	9	-
12	54	1	6	6	10	31	36	36	40	16	21	21	25	1	3	0	-	-	-	9	9	18	-
14	63	1	6	6	10	22	27	27	31	43	48	48	52	1	3	0	15	15	15	-	-	-	-
16	72	1	6	6	10	49	54	54	58	25	30	30	34	1	3	0	-	-	-	18	18	18	-
18	81	1	6	6	10	49	54	54	58	25	30	30	34	1	3	0	-	-	-	18	18	27	-
20	90	1	6	6	10	31	36	36	40	61	66	66	70	1	3	0	24	24	24	-	-	-	-
22	99	1	6	6	10	67	72	72	76	34	39	39	43	1	3	0	-	-	-	27	27	27	-
24	108	1	6	6	10	67	72	72	76	34	39	39	43	1	3	0	-	-	-	27	27	36	-

TABLE NO. 6-2

CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 2

Back Pitch = 6 Slot Pitches   Front Pitch = 6 Slot Pitchs

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Short Front Pitch Coils Between A_1 and A_2 B_1 and B_2 C_1 and C_2	No.of Normal Front Pitch Coils Between A_2 and A_4 B_2 and B_4 C_2 and C_4	No.of Short Front Pitch Coils Between A_4 and A_3 B_4 and B_3 C_4 and C_3	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads					A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	24	1	7	8	14	17	23	24	6	9	15	16	22	1	4	1	-	-	-	0	0	0	
6	36	1	7	8	14	17	23	24	30	9	15	16	22	1	4	1	-	-	-	0	0	12	6-17
8	48	1	7	8	14	17	23	24	30	33	39	40	46	1	4	1	8	8	8	-	-	-	6-25
10	60	1	7	8	14	41	47	48	54	21	27	28	34	1	4	1	-	-	-	12	12	12	6-32
12	72	1	7	8	14	41	47	48	54	21	27	28	34	1	4	1	-	-	-	12	12	24	6-38
14	84	1	7	8	14	29	35	36	42	57	63	64	70	1	4	1	20	20	20	-	-	-	6-43
16	96	1	7	8	14	65	71	72	78	33	39	40	46	1	4	1	-	-	-	24	24	24	6-48
18	108	1	7	8	14	65	71	72	78	33	39	40	46	1	4	1	-	-	-	24	24	36	6-52
20	120	1	7	8	14	41	47	48	54	81	87	88	94	1	4	1	32	32	32	-	-	-	6-56
22	132	1	7	8	14	89	95	96	102	45	51	52	58	1	4	1	-	-	-	36	36	36	6-59
24	144	1	7	8	14	89	95	96	102	45	51	52	58	1	4	1	-	-	-	36	36	48	6-62

TABLE NO. 6-3

CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 2-1/2

Back Pitch = 8 Slot Pitches   Front Pitch = 7 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No. of Short Front Pitch Coils Between A_1 and A_2 B_1 and B_2 C_1 and C_2	No. of Normal Front Pitch Coils Between A_2 and A_4 B_2 and B_4 C_2 and C_4	No. of Short Front Pitch Coils Between A_4 and A_3 B_4 and B_3 C_4 and C_3	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads					A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	30	1	9	10	17	21	29	30	7	11	19	20	27	2	5	1	-	-	-	0	0	0	
6	45	1	9	10	17	21	29	30	37	11	19	20	27	2	5	1	-	-	-	0	0	15	6-18
8	60	1	9	10	17	21	29	30	37	41	49	50	57	2	5	1	10	10	10	-	-	-	6-26
10	75	1	9	10	17	51	59	60	67	26	34	35	42	2	5	1	-	-	-	15	15	15	6-33
12	90	1	9	10	17	51	59	60	67	26	34	35	42	2	5	1	-	-	-	15	15	30	6-39
14	105	1	9	10	17	36	44	45	52	71	79	80	87	2	5	1	25	25	25	-	-	-	6-44
16	120	1	9	10	17	81	89	90	97	41	49	50	57	2	5	1	-	-	-	30	30	30	6-49
18	135	1	9	10	17	81	89	90	97	41	49	50	57	2	5	1	-	-	-	30	30	45	6-53
20	150	1	9	10	17	51	59	60	67	101	109	110	117	2	5	1	40	40	40	-	-	-	6-57
22	165	1	9	10	17	111	119	120	127	56	64	65	72	2	5	1	-	-	-	45	45	45	6-60
24	180	1	9	10	17	111	119	120	127	56	64	65	72	2	5	1	-	-	-	45	45	60	6-63

TABLE NO. 6-4

CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 3

Back Pitch = 9 Slot Pitches   Front Pitch = 9 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Short Front Pitch Coils Between	No.of Normal Front Pitch Coils Between	No.of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads											
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3	A_1 and A_2 B_1 and B_2 C_1 and C_2	A_2 and A_4 B_2 and B_4 C_2 and C_4	A_4 and A_3 B_4 and B_3 C_4 and C_3	A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
4	36	1	10	12	21	25	34	36	9	13	22	24	33	2	6	2	-	-	-	0	0	0	
6	54	1	10	12	21	25	34	36	45	13	22	24	33	2	6	2	-	-	-	0	0	18	6-19
8	72	1	10	12	21	25	34	36	45	49	58	60	69	2	6	2	12	12	12	-	-	-	6-27
10	90	1	10	12	21	61	70	72	81	31	40	42	51	2	6	2	-	-	-	18	18	18	6-34
12	108	1	10	12	21	61	70	72	81	31	40	42	51	2	6	2	-	-	-	18	18	36	6-40
14	126	1	10	12	21	43	52	54	63	85	94	96	105	2	6	2	30	30	30	-	-	-	6-45
16	144	1	10	12	21	97	106	108	117	49	58	60	69	2	6	2	-	-	-	36	36	36	6-50
18	162	1	10	12	21	97	106	108	117	49	58	60	69	2	6	2	-	-	-	36	36	54	6-54
20	180	1	10	12	21	61	70	72	81	121	130	132	141	2	6	2	48	48	48	-	-	-	6-58
22	198	1	10	12	21	133	142	144	153	67	76	78	87	2	6	2	-	-	-	54	54	54	6-61
24	216	1	10	12	21	133	142	144	153	67	76	78	87	2	6	2	-	-	-	54	54	72	6-64

TABLE NO. 6-5

CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 3-1/2

Back Pitch = 11 Slot Pitches   Front Pitch = 10 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Short Front Pitch Coils Between	No.of Normal Front Pitch Coils Between	No.of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		A_1 and A_2	A_2 and A_4	A_4 and A_3	A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper		B_1 and B_2	B_2 and B_4	B_4 and B_3							
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3	C_1 and C_2	C_2 and C_4	C_4 and C_3							
4	42	1	12	14	24	29	40	42	10	15	26	28	38	3	7	2	-	-	-	0	0	0	
6	63	1	12	14	24	29	40	42	52	15	26	28	38	3	7	2	-	-	-	0	0	21	6-20
8	84	1	12	14	24	29	40	42	52	57	68	70	80	3	7	2	14	14	14	-	-	-	6-28
10	105	1	12	14	24	71	82	84	94	36	47	49	59	3	7	2	-	-	-	21	21	21	6-35
12	126	1	12	14	24	71	82	84	94	36	47	49	59	3	7	2	-	-	-	21	21	42	6-41
14	147	1	12	14	24	50	61	63	73	99	110	112	122	3	7	2	35	35	35	-	-	-	6-46
16	168	1	12	14	24	113	124	126	136	57	68	70	80	3	7	2	-	-	-	42	42	42	6-51
18	189	1	12	14	24	113	124	126	136	57	68	70	80	3	7	2	-	-	-	42	42	63	6-55

TABLE NO. 6-6

CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 4

Back Pitch = 12 Slot Pitches   Front Pitch = 12 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No. of Short Front Pitch Coils Between	No. of Normal Front Pitch Coils Between	No. of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		A_1 and A_2 B_1 and B_2 C_1 and C_2	A_2 and A_4 B_2 and B_4 C_2 and C_4	A_4 and A_3 B_4 and B_3 C_4 and C_3	A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	48	1	13	16	28	33	45	48	12	17	29	32	44	3	8	3	-	-	-	0	0	0	
6	72	1	13	16	28	33	45	48	60	17	29	32	44	3	8	3	-	-	-	0	0	24	6-21
8	96	1	13	16	28	33	45	48	60	65	77	80	92	3	8	3	16	16	16	-	-	-	6-29
10	120	1	13	16	28	81	93	96	108	41	53	56	68	3	8	3	-	-	-	24	24	24	6-36
12	144	1	13	16	28	81	93	96	108	41	53	56	68	3	8	3	-	-	-	24	24	48	6-42
14	168	1	13	16	28	57	69	72	84	113	125	128	140	3	8	3	40	40	40	-	-	-	6-47

TABLE NO. 6-7. CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 4-1/2

Back Pitch = 14 Slot Pitches Front Pitch = 13 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No. of Short Front Pitch Coils Between A_1 and A_2 B_1 and B_2 C_1 and C_2	No. of Normal Front Pitch Coils Between A_2 and A_4 B_2 and B_4 C_2 and C_4	No. of Short Front Pitch Coils Between A_4 and A_3 B_4 and B_3 C_4 and C_3	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads					A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	54	1	15	18	31	37	51	54	13	19	33	36	49	4	9	3	-	-	-	0	0	0	
6	81	1	15	18	31	37	51	54	67	19	33	36	49	4	9	3	-	-	-	0	0	27	6-22
8	108	1	15	18	31	37	51	54	67	73	87	90	103	4	9	3	18	18	18	-	-	-	6-30
10	135	1	15	18	31	91	105	108	121	46	60	63	176	4	9	3	-	-	-	27	27	27	6-37
12	162	1	15	18	31	91	105	108	121	46	60	63	76	4	9	3	-	-	-	27	27	54	

TABLE NO. 6-8. CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 5

Back Pitch = 15 Slot Pitches Front Pitch = 15 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No. of Short Front Pitch Coils Between A_1 and A_2 B_1 and B_2 C_1 and C_2	No. of Normal Front Pitch Coils Between A_2 and A_4 B_2 and B_4 C_2 and C_4	No. of Short Front Pitch Coils Between A_4 and A_3 B_4 and B_3 C_4 and C_3	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads					A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	60	1	16	20	35	41	56	60	15	21	36	40	55	4	10	4	-	-	-	0	0	0	-
6	90	1	16	20	35	41	56	60	75	21	36	40	55	4	10	4	-	-	-	0	0	30	6-23
8	120	1	16	20	35	41	56	60	75	81	96	100	115	4	10	4	20	20	20	-	-	-	6-31
10	150	1	16	20	35	101	116	120	135	51	66	70	85	4	10	4	-	-	-	30	30	30	-

TABLE NO. 6-9. CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 5-1/2

Back Pitch = 17 Slot Pitches

Front Pitch = 16 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No. of Short Front Pitch Coils Between	No. of Normal Front Pitch Coils Between	No. of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads											
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3	A_1 and A_2 B_1 and B_2 C_1 and C_2	A_2 and A_4 B_2 and B_4 C_2 and C_4	A_4 and A_3 B_4 and B_3 C_4 and C_3	A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
4	66	1	18	22	38	45	62	66	16	23	40	44	60	5	11	4	-	-	-	0	0	0	-
6	99	1	18	22	38	45	62	66	72	23	40	44	60	5	11	4	-	-	-	0	0	33	-
8	132	1	18	22	38	45	62	66	82	89	106	110	126	5	11	4	22	22	22	-	-	-	-
10	165	1	18	22	38	111	128	132	148	56	73	77	93	5	11	4	-	-	-	33	33	33	-

TABLE NO. 6-10. CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 6

Back Pitch = 18 Slot Pitches

Front Pitch = 18 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No. of Short Front Pitch Coils Between	No. of Normal Front Pitch Coils Between	No. of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads											
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3	A_1 and A_2 B_1 and B_2 C_1 and C_2	A_2 and A_4 B_2 and B_4 C_2 and C_4	A_4 and A_3 B_4 and B_3 C_4 and C_3	A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
4	72	1	19	24	42	49	67	72	18	25	43	48	64	5	12	5	-	-	-	0	0	0	-
6	108	1	19	24	42	49	67	72	90	25	43	48	64	5	12	5	-	-	-	0	0	36	6-24
8	144	1	19	24	42	49	67	72	90	97	115	120	138	5	12	5	24	24	24	-	-	-	-

TABLE NO. 6-11. CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 7

Back Pitch = 21 Slot Pitches Front Pitch = 21 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Short Front Pitch Coils Between	No.of Normal Front Pitch Coils Between	No.of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		A_1 and A_2 B_1 and B_2 C_1 and C_2	A_2 and A_4 B_2 and B_4 C_2 and C_4	A_4 and A_3 B_4 and B_3 C_4 and C_3	A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	84	1	22	28	49	57	78	84	21	29	50	56	77	6	14	6	-	-	-	0	0	0	-
6	126	1	22	28	49	57	78	84	105	29	50	56	77	6	14	6	-	-	-	0	0	42	-
8	168	1	22	28	49	57	78	84	105	113	134	140	161	6	14	6	28	28	28	-	-	-	-

TABLE NO. 6-12. CONNECTION TABLE FOR RETROGRESSIVE WINDINGS WITH SPP = 8

Back Pitch = 24 Slot Pitches Front Pitch = 24 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Short Front Pitch Coils Between	No.of Normal Front Pitch Coils Between	No.of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		A_1 and A_2 B_1 and B_2 C_1 and C_2	A_2 and A_4 B_2 and B_4 C_2 and C_4	A_4 and A_3 B_4 and B_3 C_4 and C_3	A_3 and B_1	B_3 and C_1	C_3 and A_1	A_3 and C_1	C_3 and B_1	B_3 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	96	1	25	32	56	65	89	96	120	33	57	64	88	7	16	7	-	-	-	0	0	0	-
6	144	1	25	32	56	65	89	96	120	33	57	64	88	7	16	7	-	-	-	0	0	48	-
8	192	1	25	32	56	65	89	96	120	129	153	160	184	7	16	7	32	32	32	-	-	-	-

TABLE NO. 6-13

CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 1-1/2

Back Pitch = 5 Slot Pitches | Front Pitch = 4 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Long Front Pitch Coils Between A_1 and A_2 B_1 and B_2 C_1 and C_2	No.of Normal Front Pitch Coils Between A_2 and A_3 B_2 and B_3 C_2 and C_3	No.of Short Front Pitch Coils Between A_3 and A_4 B_3 and B_4 C_3 and C_4	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads					A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	18	1	6	15	1	13	18	9	13	7	12	3	7	0	3	1	-	-	-	0	0	0	-
6	27	1	6	24	1	13	18	9	13	7	12	3	7	0	3	1	-	-	-	0	0	3	-
8	36	1	6	33	1	13	18	9	13	25	30	21	25	0	3	1	6	6	6	-	-	-	-
10	45	1	6	42	1	31	36	27	31	16	21	12	16	0	3	1	-	-	-	9	9	9	-
12	54	1	6	51	1	31	36	27	31	16	21	12	16	0	3	1	-	-	-	9	9	18	-
14	63	1	6	60	1	22	27	18	22	43	48	39	43	0	3	1	15	15	15	-	-	-	-
16	72	1	6	69	1	49	54	45	49	25	30	21	25	0	3	1	-	-	-	18	18	18	-
18	81	1	6	78	1	49	54	45	49	25	30	21	25	0	3	1	-	-	-	18	18	27	-
20	90	1	6	87	1	31	36	27	31	61	66	57	61	0	3	1	24	24	24	-	-	-	-
22	99	1	6	96	1	67	72	63	67	34	39	30	34	0	3	1	-	-	-	27	27	27	-
24	108	1	6	105	1	67	72	63	67	34	39	30	34	0	3	1	-	-	-	27	27	36	-

TABLE NO. 6-14

CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 2

Back Pitch = 6 Slot Pitches   Front Pitch = 6 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Long Front Pitch Coils Between	No.of Normal Front Pitch Coils Between	No.of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		A_1 and A_2 B_1 and B_2 C_1 and C_2	A_2 and A_3 B_2 and B_3 C_2 and C_3	A_3 and A_4 B_3 and B_4 C_3 and C_4	A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	24	1	8	20	1	17	24	12	17	9	16	4	9	1	4	1	-	-	-	0	0	0	-
6	36	1	8	32	1	17	24	12	17	9	16	4	9	1	4	1	-	-	-	0	0	12	6-65
8	48	1	8	44	1	17	24	12	17	33	40	28	33	1	4	1	8	8	8	-	-	-	6-73
10	60	1	8	56	1	41	48	36	41	21	28	16	21	1	4	1	-	-	-	12	12	12	6-80
12	72	1	8	68	1	41	48	36	41	21	28	16	21	1	4	1	-	-	-	12	12	24	6-86
14	84	1	8	80	1	29	36	24	29	57	64	52	57	1	4	1	20	20	20	-	-	-	6-91
16	96	1	8	92	1	65	72	60	65	33	40	28	33	1	4	1	-	-	-	24	24	24	6-96
18	108	1	8	104	1	65	72	60	65	33	40	28	33	1	4	1	-	-	-	24	24	36	6-100
20	120	1	8	116	1	41	48	36	41	81	88	76	81	1	4	1	32	32	32	-	-	-	6-104
22	132	1	8	128	1	89	96	84	89	45	52	40	45	1	4	1	-	-	-	36	36	36	6-107
24	144	1	8	140	1	89	96	84	89	45	52	40	45	1	4	1	-	-	-	36	36	48	6-110

TABLE NO. 6-15

CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 2-1/2

Back Pitch = 8 Slot Pitches   Front Pitch = 7 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Long Front Pitch Coils Between A_1 and A_2 B_1 and B_2 C_1 and C_2	No.of Normal Front Pitch Coils Between A_2 and A_3 B_2 and B_3 C_2 and C_3	No.of Short Front Pitch Coils Between A_3 and A_4 B_3 and B_4 C_3 and C_4	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads					A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	30	1	10	25	1	21	30	15	21	11	20	5	11	1	5	2	-	-	-	0	0	0	-
6	45	1	10	40	1	21	30	15	21	11	20	5	11	1	5	2	-	-	-	0	0	15	6-66
8	60	1	10	55	1	21	30	15	21	41	50	35	41	1	5	2	10	10	10	-	-	-	6-74
10	75	1	10	70	1	51	60	45	51	26	35	20	26	1	5	2	-	-	-	15	15	15	6-81
12	90	1	10	85	1	51	60	45	51	26	35	20	26	1	5	2	-	-	-	15	15	30	6-87
14	105	1	10	100	1	36	45	30	36	71	80	65	71	1	5	2	25	25	25	-	-	-	6-92
16	120	1	10	115	1	81	90	75	81	41	50	35	41	1	5	2	-	-	-	30	30	30	6-97
18	135	1	10	130	1	81	90	75	81	41	50	35	41	1	5	2	-	-	-	30	30	45	6-101
20	150	1	10	145	1	51	60	45	51	101	110	95	101	1	5	2	40	40	40	-	-	-	6-105
22	165	1	10	160	1	111	120	105	111	56	64	50	56	1	5	2	-	-	-	45	45	45	6-108
24	180	1	10	175	1	111	120	105	111	56	64	50	56	1	5	2	-	-	-	45	45	60	6-111

TABLE NO. 6-16

CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 3

Back Pitch = 9 Slot Pitches Front Pitch = 9 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Long Front Pitch Coils Between	No.of Normal Front Pitch Coils Between	No.of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		A_1 and A_2	A_2 and A_3	A_3 and A_4	A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper		B_1 and B_2	B_2 and B_3	B_3 and B_4							
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3	C_1 and C_2	C_2 and C_3	C_3 and C_4							
4	36	1	12	30	1	25	36	18	25	13	24	6	13	2	6	2	-	-	-	0	0	0	-
6	54	1	12	48	1	25	36	18	25	13	24	6	13	2	6	2	-	-	-	0	0	18	6-67
8	72	1	12	66	1	25	36	18	25	49	60	42	49	2	6	2	12	12	12	-	-	-	6-75
10	90	1	12	84	1	61	72	54	61	31	42	24	31	2	6	2	-	-	-	18	18	18	6-82
12	108	1	12	102	1	61	72	54	61	31	42	24	31	2	6	2	-	-	-	18	18	36	6-88
14	126	1	12	120	1	43	54	36	43	85	96	78	85	2	6	2	30	30	30	-	-	-	6-93
16	144	1	12	138	1	97	108	90	97	49	60	42	49	2	6	2	-	-	-	36	36	36	6-98
18	162	1	12	156	1	97	108	90	97	49	60	42	49	2	6	2	-	-	-	36	36	54	6-102
20	180	1	12	174	1	61	72	54	61	121	132	114	121	2	6	2	48	48	48	-	-	-	6-106
22	198	1	12	192	1	133	144	126	133	67	78	60	67	2	6	2	-	-	-	54	54	54	6-109
24	216	1	12	210	1	133	144	126	133	67	78	60	67	2	6	2	-	-	-	54	54	72	6-112

TABLE NO. 6-17

CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 3-1/2

Back Pitch = 11 Slot Pitches

Front Pitch = 10 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Long Front Pitch Coils Between	No.of Normal Front Pitch Coils Between	No.of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads											
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3	A_1 and A_2 B_1 and B_2 C_1 and C_2	A_2 and A_3 B_2 and B_3 C_2 and C_3	A_3 and A_4 B_3 and B_4 C_3 and C_4	A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
4	42	1	14	35	1	29	42	21	29	15	28	7	15	2	7	3	-	-	-	0	0	0	-
6	63	1	14	56	1	29	42	21	29	15	28	7	15	2	7	3	-	-	-	0	0	21	6-68
8	84	1	14	77	1	29	42	21	29	57	70	49	57	2	7	3	14	14	14	-	-	-	6-76
10	105	1	14	98	1	71	84	63	71	36	49	28	36	2	7	3	-	-	-	21	21	21	6-83
12	126	1	14	119	1	71	84	63	71	36	49	28	36	2	7	3	-	-	-	21	21	42	6-89
14	147	1	14	140	1	50	63	42	50	99	112	91	99	2	7	3	35	35	35	-	-	-	6-94
16	168	1	14	161	1	113	126	105	113	57	70	49	57	2	7	3	-	-	-	42	42	42	6-99
18	189	1	14	182	1	113	126	105	113	57	70	49	57	2	7	3	-	-	-	42	42	63	6-103

TABLE NO. 6-18

CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 4

Back Pitch = 12 Slot Pitches Front Pitch = 12 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No. of Long Front Pitch Coils Between	No. of Normal Front Pitch Coils Between	No. of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads		A_1 and A_2 B_1 and B_2 C_1 and C_2	A_2 and A_3 B_2 and B_3 C_2 and C_3	A_3 and A_4 B_3 and B_4 C_3 and C_4	A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	48	1	16	40	1	33	48	24	33	17	32	8	17	3	8	3	-	-	-	0	0	0	-
6	72	1	16	64	1	33	48	24	33	17	32	8	17	3	8	3	-	-	-	0	0	24	6-69
8	96	1	16	88	1	33	48	24	33	65	80	56	65	3	8	3	16	16	16	-	-	-	6-77
10	120	1	16	112	1	81	96	72	81	41	56	32	41	3	8	3	-	-	-	24	24	24	6-84
12	144	1	16	136	1	81	96	72	81	41	56	32	41	3	8	3	-	-	-	24	24	48	6-90
14	168	1	16	160	1	57	72	48	57	113	128	104	113	3	8	3	40	40	40	-	-	-	6-95

TABLE NO. 6-19. CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 4-1/2

Back Pitch = 14 Slot Pitches

Front Pitch = 13 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Long Front Pitch Coils Between A_1 and A_2 B_1 and B_2 C_1 and C_2	No.of Normal Front Pitch Coils Between A_2 and A_3 B_2 and B_3 C_2 and C_3	No.of Short Front Pitch Coils Between A_3 and A_4 B_3 and B_4 C_3 and C_4	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads					A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	54	1	18	45	1	37	54	27	37	19	36	9	19	3	9	4	-	-	-	0	0	0	-
6	81	1	18	72	1	37	54	27	37	19	36	9	19	3	9	4	-	-	-	0	0	27	6-70
8	108	1	18	99	1	37	54	27	37	73	90	63	73	3	9	4	18	18	18	-	-	-	6-78
10	135	1	18	126	1	91	108	81	91	46	63	36	46	3	9	4	-	-	-	27	27	27	6-85
12	162	1	18	153	1	91	108	81	91	46	63	36	46	3	9	4	-	-	-	27	27	54	-

TABLE NO. 6-20. CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 5

Back Pitch = 15 Slot Pitches

Front Pitch = 15 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Long Front Pitch Coils Between A_1 and A_2 B_1 and B_2 C_1 and C_2	No.of Normal Front Pitch Coils Between A_2 and A_3 B_2 and B_3 C_2 and C_3	No.of Short Front Pitch Coils Between A_3 and A_4 B_3 and B_4 C_3 and C_4	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads					A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	60	1	20	50	1	41	60	30	41	21	40	10	21	4	10	4	-	-	-	0	0	0	-
6	90	1	20	80	1	41	60	30	41	21	40	10	21	4	10	4	-	-	-	0	0	30	6-71
8	120	1	20	110	1	41	60	30	41	81	100	70	81	4	10	4	20	20	20	-	-	-	6-79
10	150	1	20	140	1	101	120	90	101	51	70	40	51	4	10	4	-	-	-	30	30	30	-

TABLE NO. 6-21. CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 5-1/2

Back Pitch = 17 Slot Pitches

Front Pitch = 16 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Long Front Pitch Coils Between A_1 and A_2 B_1 and B_2 C_1 and C_2	No.of Normal Front Pitch Coils Between A_2 and A_3 B_2 and B_3 C_2 and C_3	No.of Short Front Pitch Coils Between A_3 and A_4 B_3 and B_4 C_3 and C_4	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads					A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	66	1	22	55	1	45	66	33	45	23	44	11	23	4	11	5	-	-	-	0	0	0	-
6	99	1	22	88	1	45	66	33	45	23	44	11	23	4	11	5	-	-	-	0	0	33	-
8	132	1	22	121	1	45	66	33	45	89	110	77	89	4	11	5	22	22	22	-	-	-	-
10	165	1	22	154	1	111	132	99	111	56	77	44	56	4	11	5	-	-	-	33	33	33	-

TABLE NO. 6-22. CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 6

Back Pitch = 18 Slot Pitches

Front Pitch = 18 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Long Front Pitch Coils Between A_1 and A_2 B_1 and B_2 C_1 and C_2	No.of Normal Front Pitch Coils Between A_2 and A_3 B_2 and B_3 C_2 and C_3	No.of Short Front Pitch Coils Between A_3 and A_4 B_3 and B_4 C_3 and C_4	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads					A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper											
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3										
4	72	1	24	60	1	49	72	36	49	25	48	12	25	5	12	5	-	-	-	0	0	0	-
6	108	1	24	96	1	49	72	36	49	25	48	12	25	5	12	5	-	-	-	0	0	36	6-72
8	144	1	24	132	1	49	72	36	49	97	120	84	97	5	12	5	24	24	24	-	-	-	-

TABLE NO. 6-23. CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 7

Back Pitch = 21 Slot Pitches

Front Pitch = 21 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Long Front Pitch Coils Between	No.of Normal Front Pitch Coils Between	No.of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads											
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper		A_1 and A_2	A_2 and A_3	A_3 and A_4	A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3	B_1 and B_2 C_1 and C_2	B_2 and B_3 C_2 and C_3	B_3 and B_4 C_3 and C_4							
4	84	1	28	70	1	57	84	42	57	29	56	14	29	6	14	6	-	-	-	0	0	0	-
6	126	1	28	112	1	57	84	42	57	29	56	14	29	6	14	6	-	-	-	0	0	42	-
8	168	1	28	154	1	57	84	42	57	113	140	98	113	6	14	6	28	28	28	-		-	-

TABLE NO. 6-24. CONNECTION TABLE FOR PROGRESSIVE - RETROGRESSIVE WINDINGS WITH SPP = 8

Back Pitch = 24 Slot Pitches

Front Pitch = 24 Slot Pitches

No. of Poles	No. of Slots	PHASE A				PHASE B				PHASE C				No.of Long Front Pitch Coils Between	No.of Normal Front Pitch Coils Between	No.of Short Front Pitch Coils Between	NO. OF NORMAL FRONT PITCH COILS BETWEEN						REFERENCE FIGURE
		Top Leads		Bottom Leads		Top Leads		Bottom Leads		Top Leads		Bottom Leads											
		Start	End	Reversing Jumper		Start	End	Reversing Jumper		Start	End	Reversing Jumper		A_1 and A_2	A_2 and A_3	A_3 and A_4	A_4 and B_1	B_4 and C_1	C_4 and A_1	A_4 and C_1	C_4 and B_1	B_4 and A_1	
		A_1	A_4	A_2	A_3	B_1	B_4	B_2	B_3	C_1	C_4	C_2	C_3	B_1 and B_2 C_1 and C_2	B_2 and B_3 C_2 and C_3	B_3 and B_4 C_3 and C_4							
4	96	1	32	80	1	65	96	48	65	33	64	16	33	7	16	7	-	-	-	0	0	0	-
6	144	1	32	128	1	65	96	48	65	33	64	16	33	7	16	7	-	-	-	0	0	48	-
8	192	1	32	176	1	65	96	48	65	129	160	112	129	7	16	7	32	32	32	-	-	-	-

TABLE 6-25

DISTRIBUTION TABLE OF THE LOWER CONDUCTORS FOR spp = 1½

No. Slots	No. Poles	Phase A		Phase C		Phase B		Polarity
		1	2	3		4	5	↑
		6		7	8	9		↓
		10	11	12		13	14	↑
18	4	15		16	17	18		↓
		19	20	21		22	23	↑
27	6	24		25	26	27		↓
		28	29	30		31	32	↑
36	8	33		34	35	36		↓
		37	38	39		40	41	↑
45	10	42		43	44	45		↓
		46	47	48		49	50	↑
54	12	51		52	53	54		↓
		55	56	57		58	59	↑
63	14	60		61	62	63		↓
		64	65	66		67	68	↑
72	16	69		70	71	72		↓
		73	74	75		76	77	↑
81	18	78		79	80	81		↓
		82	83	84		85	86	↑
90	20	87		88	89	90		↓
		91	92	93		94	95	↑
99	22	96		97	98	99		↓
		100	101	102		103	104	↑
108	24	105		106	107	108		↓

TABLE 6-26

DISTRIBUTION TABLE OF THE UPPER CONDUCTORS FOR spp = 1½

No. Slots	No. Poles	Phase A		Phase C		Phase B		Polarity
		1		2	3	4		↑
		5	6	7		8	9	↓
		10		11	12	13		↑
18	4	14	15	16		17	18	↓
		19		20	21	22		↑
27	6	23	24	25		26	27	↓
		28		29	30	31		↑
36	8	32	33	34		35	36	↓
		37		38	39	40		↑
45	10	41	42	43		44	45	↓
		46		47	48	49		↑
54	12	50	51	52		53	54	↓
		55		56	57	58		↑
63	14	59	60	61		62	63	↓
		64		65	66	67		↑
72	16	68	69	70		71	72	↓
		73		74	75	76		↑
81	18	77	78	79		80	81	↓
		82		83	84	85		↑
90	20	86	87	88		89	90	↓
		91		92	93	94		↑
99	22	95	96	97		98	99	↓
		100		101	102	103		↑
108	24	104	105	106		107	108	↓

TABLE 6-27

DISTRIBUTION TABLE OF THE UPPER AND LOWER CONDUCTORS FOR spp = 2

No. Slots	No. Poles	Phase A		Phase C		Phase B		Polarity
		1	2	3	4	5	6	↑
		7	8	9	10	11	12	↓
		13	14	15	16	17	18	↑
24	4	19	20	21	22	23	24	↓
		25	26	27	28	29	30	↑
36	6	31	32	33	34	35	36	↓
		37	38	39	40	41	42	↑
48	8	43	44	45	46	47	48	↓
		49	50	51	52	53	54	↑
60	10	55	56	57	58	59	60	↓
		61	62	63	64	65	66	↑
72	12	67	68	69	70	71	72	↓
		73	74	75	76	77	78	↑
84	14	79	80	81	82	83	84	↓
		85	86	87	88	89	90	↑
96	16	91	92	93	94	95	96	↓
		97	98	99	100	101	102	↑
108	18	103	104	105	106	107	108	↓
		109	110	111	112	113	114	↑
120	20	115	116	117	118	119	120	↓
		121	122	123	124	125	126	↑
132	22	127	128	129	130	131	132	↓
		133	134	135	136	137	138	↑
144	24	139	140	141	142	143	144	↓

TABLE 6-28

DISTRIBUTION TABLE OF THE LOWER CONDUCTORS FOR spp = 2½

No. Slots	No. Poles	Phase A			Phase C			Phase B			Polarity
		1	2	3	4	5		6	7	8	↑
		9	10		11	12	13	14	15		↓
		16	17	18	19	20		21	22	23	↑
30	4	24	25		26	27	28	29	30		↓
		31	32	33	34	35		36	37	38	↑
45	6	39	40		41	42	43	44	45		↓
		46	47	48	49	50		51	52	53	↑
60	8	54	55		56	57	58	59	60		↓
		61	62	63	64	65		66	67	68	↑
75	10	69	70		71	72	73	74	75		↓
		76	77	78	79	80		81	82	83	↑
90	12	84	85		86	87	88	89	90		↓
		91	92	93	94	95		96	97	98	↑
105	14	99	100		101	102	103	104	105		↓
		106	107	108	109	110		111	112	113	↑
120	16	114	115		116	117	118	119	120		↓
		121	122	123	124	125		126	127	128	↑
135	18	129	130		131	132	133	134	135		↓
		136	137	138	139	140		141	142	143	↑
150	20	144	145		146	147	148	149	150		↓
		151	152	153	154	155		156	157	158	↑
165	22	159	160		161	162	163	164	165		↓
		166	167	168	169	170		171	172	173	↑
180	24	174	175		176	177	178	179	180		↓

TABLE 6-29

DISTRIBUTION TABLE OF THE UPPER CONDUCTORS FOR spp = 2½

No. Slots	No. Poles	Phase A			Phase C			Phase B			Polarity
		1	2		3	4	5	6	7		↑
		8	9	10	11	12		13	14	15	↓
		16	17		18	19	20	21	22		↑
30	4	23	24	25	26	27		28	29	30	↓
		31	32		33	34	35	36	37		↑
45	6	38	39	40	41	42		43	44	45	↓
		46	47		48	49	50	51	52		↑
60	8	53	54	55	56	57		58	59	60	↓
		61	62		63	64	65	66	67		↑
75	10	68	69	70	71	72		73	74	75	↓
		76	77		78	79	80	81	82		↑
90	12	83	84	85	86	87		88	89	90	↓
		91	92		93	94	95	96	97		↑
105	14	98	99	100	101	102		103	104	105	↓
		106	107		108	109	110	111	112		↑
120	16	113	114	115	116	117		118	119	120	↓
		121	122		123	124	125	126	127		↑
135	18	128	129	130	131	132		133	134	135	↓
		136	137		138	139	140	141	142		↑
150	20	143	144	145	146	147		148	149	150	↓
		151	152		153	154	155	156	157		↑
165	22	158	159	160	161	162		163	164	165	↓
		166	167		168	169	170	171	172		↑
180	24	173	174	175	176	177		178	179	180	↓

TABLE 6-30

DISTRIBUTION TABLE OF THE UPPER AND LOWER CONDUCTORS FOR spp = 3

No. Slots	No. Poles	Phase A			Phase C			Phase B			Polarity
		1	2	3	4	5	6	7	8	9	↑
		10	11	12	13	14	15	16	17	18	↓
		19	20	21	22	23	24	25	26	27	↑
36	4	28	29	30	31	32	33	34	35	36	↓
		37	38	39	40	41	42	43	44	45	↑
54	6	46	47	48	49	50	51	52	53	54	↓
		55	56	57	58	59	60	61	62	63	↑
72	8	64	65	66	67	68	69	70	71	72	↓
		73	74	75	76	77	78	79	80	81	↑
90	10	82	83	84	85	86	87	88	89	90	↓
		91	92	93	94	95	96	97	98	99	↑
108	12	100	101	102	103	104	105	106	107	108	↓
		109	110	111	112	113	114	115	116	117	↑
126	14	118	119	120	121	122	123	124	125	126	↓
		127	128	129	130	131	132	133	134	135	↑
144	16	136	137	138	139	140	141	142	143	144	↓
		145	146	147	148	149	150	151	152	153	↑
162	18	154	155	156	157	158	159	160	161	162	↓
		163	164	165	166	167	168	169	170	171	↑
180	20	172	173	174	175	176	177	178	179	180	↓
		181	182	183	184	185	186	187	188	189	↑
198	22	190	191	192	193	194	195	196	197	198	↓
		199	200	201	202	203	204	205	206	207	↑
216	24	208	209	210	211	212	213	214	215	216	↓

TABLE 6-31

DISTRIBUTION TABLE OF THE LOWER CONDUCTORS FOR spp = 3½

No. Slots	No. Poles	Phase A				Phase C				Phase B				Polarity
		1	2	3	4	5	6	7		8	9	10	11	↑
		12	13	14		15	16	17	18	19	20	21		↓
		22	23	24	25	26	27	28		29	30	31	32	↑
42	4	33	34	35		36	37	38	39	40	41	42		↓
		43	44	45	46	47	48	49		50	51	52	53	↑
63	6	54	55	56		57	58	59	60	61	62	63		↓
		64	65	66	67	68	69	70		71	72	73	74	↑
84	8	75	76	77		78	79	80	81	82	83	84		↓
		85	86	87	88	89	90	91		92	93	94	95	↑
105	10	96	97	98		99	100	101	102	103	104	105		↓
		106	107	108	109	110	111	112		113	114	115	116	↑
126	12	117	118	119		120	121	122	123	124	125	126		↓
		127	128	129	130	131	132	133		134	135	136	137	↑
147	14	138	139	140		141	142	143	144	145	146	147		↓
		148	149	150	151	152	153	154		155	156	157	158	↑
168	16	159	160	161		162	163	164	165	166	167	168		↓
		169	170	171	172	173	174	175		176	177	178	179	↑
189	18	180	181	182		183	184	185	186	187	188	189		↓

TABLE 6-32

DISTRIBUTION TABLE OF THE UPPER CONDUCTORS FOR spp = 3½

No. Slots	No. Poles	Phase A				Phase C				Phase B				Polarity
		1	2	3		4	5	6	7	8	9	10		↑
		11	12	13	14	15	16	17		18	19	20	21	↓
		22	23	24		25	26	27	28	29	30	31		↑
42	4	32	33	34	35	36	37	38		39	40	41	42	↓
		43	44	45		46	47	48	49	50	51	52		↑
63	6	53	54	55	56	57	58	59		60	61	62	63	↓
		64	65	66		67	68	69	70	71	72	73		↑
84	8	74	75	76	77	78	79	80		81	82	83	84	↓
		85	86	87		88	89	90	91	92	93	94		↑
105	10	95	96	97	98	99	100	101		102	103	104	105	↓
		106	107	108		109	110	111	112	113	114	115		↑
126	12	116	117	118	119	120	121	122		123	124	125	126	↓
		127	128	129		130	131	132	133	134	135	136		↑
147	14	137	138	139	140	141	142	143		144	145	146	147	↓
		148	149	150		151	152	153	154	155	156	157		↑
168	16	158	159	160	161	162	163	164		165	166	167	168	↓
		169	170	171		172	173	174	175	176	177	178		↑
189	18	179	180	181	182	183	184	185		186	187	188	189	↓

TABLE 6-33

DISTRIBUTION TABLE OF THE UPPER AND LOWER CONDUCTORS FOR spp = 4

No. Slots	No. Poles	Phase A				Phase C				Phase B				Polarity
		1	2	3	4	5	6	7	8	9	10	11	12	↑
		13	14	15	16	17	18	19	20	21	22	23	24	↓
		25	26	27	28	29	30	31	32	33	34	35	36	↑
48	4	37	38	39	40	41	42	43	44	45	46	47	48	↓
		49	50	51	52	53	54	55	56	57	58	59	60	↑
72	6	61	62	63	64	65	66	67	68	69	70	71	72	↓
		73	74	75	76	77	78	79	80	81	82	83	84	↑
96	8	85	86	87	88	89	90	91	92	93	94	95	96	↓
		97	98	99	100	101	102	103	104	105	106	107	108	↑
120	10	109	110	111	112	113	114	115	116	117	118	119	120	↓
		121	122	123	124	125	126	127	128	129	130	131	132	↑
144	12	133	134	135	136	137	138	139	140	141	142	143	144	↓
		145	146	147	148	149	150	151	152	153	154	155	156	↑
168	14	157	158	159	160	161	162	163	164	165	166	167	168	↓

TABLE 6-34

DISTRIBUTION TABLE OF THE LOWER CONDUCTORS FOR spp = 4½

No. Slots	No. Poles	Phase A					Phase C					Phase B					Polarity
		1	2	3	4	5	6	7	8	9		10	11	12	13	14	↑
		15	16	17	18		19	20	21	22	23	24	25	26	27		↓
		28	29	30	31	32	33	34	35	36		37	38	39	40	41	↑
54	4	42	43	44	45		46	47	48	49	50	51	52	53	54		↓
		55	56	57	58	59	60	61	62	63		64	65	66	67	68	↑
81	6	69	70	71	72		73	74	75	76	77	78	79	80	81		↓
		82	83	84	85	86	87	88	89	90		91	92	93	94	95	↑
108	8	96	97	98	99		100	101	102	103	104	105	106	107	108		↓
		109	110	111	112	113	114	115	116	117		118	119	120	121	122	↑
135	10	123	124	125	126		127	128	129	130	131	132	133	134	135		↓
		136	137	138	139	140	141	142	143	144		145	146	147	148	149	↑
162	12	150	151	152	153		154	155	156	157	158	159	160	161	162		↓

TABLE 6-35
DISTRIBUTION TABLE OF THE UPPER CONDUCTORS FOR spp = 4½

No. Slots	No. Poles	Phase A					Phase C					Phase B					Polarity
		1	2	3	4		5	6	7	8	9	10	11	12	13		↑
		14	15	16	17	18	19	20	21	22		23	24	25	26	27	↓
		28	29	30	31		32	33	34	35	36	37	38	39	40		↑
54	4	41	42	43	44	45	46	47	48	49		50	51	52	53	54	↓
		55	56	57	58		59	60	61	62	63	64	65	66	67		↑
81	6	68	69	70	71	72	73	74	75	76		77	78	79	80	81	↓
		82	83	84	85		86	87	88	89	90	91	92	93	94		↑
108	8	95	96	97	98	99	100	101	102	103		104	105	106	107	108	↓
		109	110	111	112		113	114	115	116	117	118	119	120	121		↑
135	10	122	123	124	125	126	127	128	129	130		131	132	133	134	135	↓
		136	137	138	139		140	141	142	143	144	145	146	147	148		↑
162	12	149	150	151	152	153	154	155	156	157		158	159	160	161	162	↓

TABLE 6-36

DISTRIBUTION TABLE OF THE UPPER AND LOWER CONDUCTORS FOR spp = 5

No. Slots	No. Poles	Phase A					Phase C					Phase B					Polarity
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	↑
		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	↓
		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	↑
60	4	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	↓
		61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	↑
90	6	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	↓
		91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	↑
120	8	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	↓
		121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	↑
150	10	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	↓

TABLE 6-37

DISTRIBUTION TABLE OF THE LOWER CONDUCTORS FOR spp = 5½

No. Slots	No. Poles	Phase A	Phase C	Phase B	Polarity
		1 2 3 4 5 6	7 8 9 10 11	12 13 14 15 16 17	↑
		18 19 20 21 22	23 24 25 26 27 28	29 30 31 32 33	↓
		34 35 36 37 38 39	40 41 42 43 44	45 46 47 48 49 50	↑
66	4	51 52 53 54 55	56 57 58 59 60 61	62 63 64 65 66	↓
		67 68 69 70 71 72	73 74 75 76 77	78 79 80 81 82 83	↑
99	6	84 85 86 87 88	89 90 91 92 93 94	95 96 97 98 99	↓
		100 101 102 103 104 105	106 107 108 109 110	111 112 113 114 115 116	↑
132	8	117 118 119 120 121	122 123 124 125 126 127	128 129 130 131 132	↓
		133 134 135 136 137 138	139 140 141 142 143	144 145 146 147 148 149	↑
165	10	150 151 152 153 154	155 156 157 158 159 160	161 162 163 164 165	↓

TABLE 6-38

DISTRIBUTION TABLE OF THE UPPER CONDUCTORS FOR spp = 5½

No. Slots	No. Poles	Phase A	Phase C	Phase B	Polarity
		1 2 3 4 5	6 7 8 9 10 11	12 13 14 15 16	↑
		17 18 19 20 21 22	23 24 25 26 27	28 29 30 31 32 33	↓
		34 35 36 37 38	39 40 41 42 43 44	45 46 47 48 49	↑
66	4	50 51 52 53 54 55	56 57 58 59 60	61 62 63 64 65 66	↓
		67 68 69 70 71	72 73 74 75 76 77	78 79 80 81 82	↑
99	6	83 84 85 86 87 88	89 90 91 92 93	94 95 96 97 98 99	↓
		100 101 102 103 104	105 106 107 108 109 110	111 112 113 114 115	↑
132	8	116 117 118 119 120 121	122 123 124 125 126	127 128 129 130 131 132	↓
		133 134 135 136 137	138 139 140 141 142 143	144 145 146 147 148	↑
165	10	149 150 151 152 153 154	155 156 157 158 159	160 161 162 163 164 165	↓

TABLE 6-39

DISTRIBUTION TABLE OF THE UPPER AND LOWER CONDUCTORS FOR spp = 6

No. Slots	No. Poles	Phase A	Phase C	Phase B	Polarity
		1 2 3 4 5 6	7 8 9 10 11 12	13 14 15 16 17 18	↑
		19 20 21 22 23 24	25 26 27 28 29 30	31 32 33 34 35 36	↓
		37 38 39 40 41 42	43 44 45 46 47 48	49 50 51 52 53 54	↑
72	4	55 56 57 58 59 60	61 62 63 64 65 66	67 68 69 70 71 72	↓
		73 74 75 76 77 78	79 80 81 82 83 84	85 86 87 88 89 90	↑
108	6	91 92 93 94 95 96	97 98 99 100 101 102	103 104 105 106 107 108	↓
		109 110 111 112 113 114	115 116 117 118 119 120	121 122 123 124 125 126	↑
144	8	127 128 129 130 131 132	133 134 135 136 137 138	139 140 141 142 143 144	↓

TABLE 6-40

DISTRIBUTION TABLE OF THE UPPER AND LOWER CONDUCTORS FOR spp = 7

No. Slots	No. Poles	Phase A	Phase C	Phase B	Polarity
		1 2 3 4 5 6 7	8 9 10 11 12 13 14	15 16 17 18 19 20 21	↑
		22 23 24 25 26 27 28	29 30 31 32 33 34 35	36 37 38 39 40 41 42	↓
		43 44 45 46 47 48 49	50 51 52 53 54 55 56	57 58 59 60 61 62 63	↑
84	4	64 65 66 67 68 69 70	71 72 73 74 75 76 77	78 79 80 81 82 83 84	↓
		85 86 87 88 89 90 91	92 93 94 95 96 97 98	99 100 101 102 103 104 105	↑
126	6	106 107 108 109 110 111 112	113 114 115 116 117 118 119	120 121 122 123 124 125 126	↓
		127 128 129 130 131 132 133	134 135 136 137 138 139 140	141 142 143 144 145 146 147	↑
168	8	148 149 150 151 152 153 154	155 156 157 158 159 160 161	162 163 164 165 166 167 168	↓

TABLE 6-41

DISTRIBUTION TABLE OF THE UPPER AND LOWER CONDUCTORS FOR spp = 8

No. Slots	No. Poles	Phase A	Phase C	Phase B	Polarity
		1 2 3 4 5 6 7 8	9 10 11 12 13 14 15 16	17 18 19 20 21 22 23 24	↑
		25 26 27 28 29 30 31 32	33 34 35 36 37 38 39 40	41 42 43 44 45 46 47 48	↓
		49 50 51 52 53 54 55 56	57 58 59 60 61 62 63 64	65 66 67 68 69 70 71 72	↑
96	4	73 74 75 76 77 78 79 80	81 82 83 84 85 86 87 88	89 90 91 92 93 94 95 96	↓
		97 98 99 100 101 102 103 104	105 106 107 108 109 110 111 112	113 114 115 116 117 118 119 120	↑
144	6	121 122 123 124 125 126 127 128	129 130 131 132 133 134 135 136	137 138 139 140 141 142 143 144	↓
		145 146 147 148 149 150 151 152	153 154 155 156 157 158 159 160	161 162 163 164 165 166 167 168	↑
192	8	169 170 171 172 173 174 175 176	177 178 179 180 181 182 183 184	185 186 187 188 189 190 191 192	↓

TABLE 6-42, SERIES STAR, SERIES DELTA, 2-PARALLEL STAR AND 2-PARALLEL DELTA CONNECTIONS

FOR spp = INTEGER OR (INTEGER + ½)						
TYPE OF CONNECTION	SLIP RING OR LINE CONNECTION			REVERSING JUMPERS	STAR POINT	REF. FIGURE
	T_1	T_2	T_3			
SERIES STAR	A_1	B_1	C_1	$A_2 \longrightarrow A_3$ $B_2 \longrightarrow B_3$ $C_2 \longrightarrow C_3$	$A_4 \longrightarrow B_4 \longrightarrow C_4$	6-117
SERIES DELTA	$A_1 \longrightarrow B_4$ or $A_1 \longrightarrow C_4$	$B_1 \longrightarrow C_4$ or $B_1 \longrightarrow A_4$	$C_1 \longrightarrow A_4$ or $C_1 \longrightarrow B_4$	$A_2 \longrightarrow A_3$ $B_2 \longrightarrow B_3$ $C_2 \longrightarrow C_3$	. . . .	6-118
FOR spp = INTEGER ONLY						
2 PARALLEL STAR	$A_1 \longrightarrow A_3$	$B_1 \longrightarrow B_3$	$C_1 \longrightarrow C_3$	. . . . .	$A_2 \rightarrow A_4 \rightarrow B_2 \rightarrow B_4 \rightarrow C_2 \rightarrow C_4$	6-119
2 PARALLEL DELTA	$A_1 \rightarrow A_3 \rightarrow C_2 \rightarrow C_4$ or $A_1 \rightarrow A_3 \rightarrow B_2 \rightarrow B_4$	$B_1 \rightarrow B_3 \rightarrow A_2 \rightarrow A_4$ or $B_1 \rightarrow B_3 \rightarrow C_2 \rightarrow C_4$	$C_1 \rightarrow C_3 \rightarrow B_2 \rightarrow B_4$ or $C_1 \rightarrow C_3 \rightarrow A_2 \rightarrow A_4$	. . . .		6-120

CHAPTER 7

BALANCED FRACTIONAL-SLOT WAVE WINDINGS

7-1. Features of the Windings Treated in This Chapter. Only windings with a fractional spp are treated in this chapter, as for example, windings with spp = 2 1/5, 2 3/7, 2 3/8, and so on. However, not all fractional-slot windings are considered here. The windings with spp = (integer + 1/2) were dealt with in Chapter 6. Of the other windings with fractional spp, only those will be treated which yield balanced windings in the sense defined in Art. 4-6, i.e., only those will be considered in which the denominator is not divisible by the number of phases 3. Thus, for example, a winding with spp = 2 5/6 is out of the scope of this chapter, because the denominator of the fraction 6 is divisible by 3. Further, the windings dealt with in this chapter must have a number of slots which is divisible by the number of phases 3, since this also is a condition for balance (see Art. 4-6).

So far as spp is concerned, the windings treated in this chapter are the same as those treated in Chapter 4 on balanced fractional-slot lap windings and, for the same value of spp, the coil grouping is exactly the same as there (see Table 4-2). However, because of the wave arrangement of the winding, other rules for the connections between coils must be applied.

The wave windings considered in the foregoing chapter, i.e., the windings with spp = integer or (integer + 1/2), are made up of coil series each of which consists of as many coils as there are pole pairs, and a certain number of abnormal front pitches are necessary, in order to connect the coil series together. The windings treated in this chapter have no abnormal front pitches. On the other hand, a large part of the windings treated here have more connections between winding parts than the integral-slot or (integral + 1/2)-slot windings.

As the Master Table 3-5 shows, the windings falling in the range of this chapter are so numerous that Connection Tables and Working Diagrams could not be given for all of them. For this reason, Connection Tables and Working Diagrams will be given for only a limited number of spp, and in several articles (Arts. 7-4 to 7-10) general methods will be explained which show how to lay out the winding and set up its Connection Table and Working Diagram for any value of spp considered in this chapter.

Note that the following tables, diagrams, and general methods are based on left-hand coils, as has been done in the previous chapters. Further, 2 conductors per slot, i.e., one in each layer, will be assumed. If the number of conductors in each layer is larger than 1, the layout of the winding is to be based on a fictitious number of slots which is equal to the real number of slots times the numbers of conductors per layer. The value of spp is then determined by the fictitious number of slots, (see Art. 6-6).

7-2. Connection Tables and How to Use Them. The use of the Connection Tables will be explained by an example. A winding with 180 slots and 28 poles will be considered. The Master Table 3-5 yields for 180 slots and 28 poles an spp = 2 1/7. Connection Table 7-7 refers to this value of spp. Each phase consists of 4 repeatable parts, each part having 15 coils. All parts start in upper conductors and end in lower ones and must be wound in a clockwise direction. The back pitch is equal to 6 slot pitches, and the front pitch to 7 slot pitches. The starts of each repeatable part, designated by odd subscripts, and the ends of each repeatable part, designated by even subscripts, lie in the conductors shown below:

Phase A		Phase B		Phase C	
Starts Upper Cond.	Ends Lower Cond.	Starts Upper Cond.	Ends Lower Cond.	Starts Upper Cond.	Ends Lower Cond.
A_1 = 1	A_2 = 9	B_1 = 31	B_2 = 39	C_1 = 16	C_2 = 24
A_3 = 46	A_4 = 54	B_3 = 76	B_4 = 84	C_3 = 61	C_4 = 69
A_5 = 91	A_6 = 99	B_5 = 121	B_6 = 129	C_5 = 106	C_6 = 114
A_7 = 136	A_8 = 144	B_7 = 166	B_8 = 174	C_7 = 151	C_8 = 159

In order to lay out a part of the winding, for example, part 1 of phase A lying between upper conductor 1 (A_1) and lower conductor 9 (A_2), start with upper conductor 1 which is connected with lower conductor (1 + back pitch) = 1 + 6 = 7. This lower conductor 7 is then connected with upper conductor (7 + front pitch) = 7 + 7 = 14, which connects with lower conductor 14 + 6 = 20. Connect this latter conductor with the upper conductor 20 + 7 = 27. In this way, the first 3 coils are connected in series. Continue until all 15 coils (in general, all N = numerator of spp coils) of part 1 are connected together. Repeat the same process with all other parts starting with the conductors A_3, A_5, A_7, B_1, B_3, and so forth.

The Connection Table 7-7 also gives complete information about the connections between the parts of each phase and between the phases for series, parallel, star, and delta connections. If, for example, 2 parallel circuits in star are desirable, the following connections are to be made in the 3 phases:

$A_1 \rightarrow A_8$ $A_2 \rightarrow A_4$ $A_5 \rightarrow A_7$ $A_3 \rightarrow A_6$
$B_4 \rightarrow B_5$ $B_1 \rightarrow B_3$ $B_6 \rightarrow B_8$ $B_2 \rightarrow B_7$
$C_2 \rightarrow C_3$ $C_1 \rightarrow C_7$ $C_4 \rightarrow C_6$ $C_5 \rightarrow C_8$

Conductors $A_3 \rightarrow A_6$, $B_2 \rightarrow B_7$, and $C_5 \rightarrow C_8$ are to be connected to the star point, and conductors $A_1 \rightarrow A_8$, $B_4 \rightarrow B_5$, and $C_2 \rightarrow C_3$, to the line or slip rings. Since there are 4 repeatable parts in each phase, a maximum of 4 parallel circuits are possible.

In the example considered, all parts have the same number of coils. This is not always the case. Consider Connection Table 7-34 for spp = 2 3/8. For 16 poles, this winding has 4 parts per phase; 2 of them are designated in phase A by $A1_1$-$A1_2$ and $A1_3$-$A1_4$, and 2 by $A2_1$-$A2_2$ and $A2_3$-$A2_4$. As the Table shows, the parts designated by A1 have 10 coils each, while the parts designated by A2 have only 9 coils each.

7-3. Working Diagrams. The Working Diagrams are similar to those developed in Chapter 6. In Chapter 6, the beginning and end of the same coil series were shown as reference points, whereas, in this chapter, the reference points are the start of a coil series of phase A and the end of a coil series of phase B. As in Chapter 6, the short radial lines represent clips, the numbers between the leads representing the starts and the ends of the winding parts indicating the number of clips or coils lying between them. The proper connection between parts for series, parallel, star or delta connections is indicated in the corresponding Connection Table.

The Working Diagrams of Chapter 6 consisted of 2 parts per phase, whereas those in this chapter vary from 2 parts per phase to 8 parts per phase, making the Working Diagram more complicated. In Chapter 6, the starts and ends of the parts were drawn to the inside of the concentric circles representing coils or clips. For the sake of clarity, the Working Diagrams in this chapter have the upper conductors (either starts or ends) identified outside of the 2 concentric circles while the lower conductors are identified inside of the circles.

Figures 7-1 to 7-43, inclusive, show working diagrams and fully developed winding diagrams and are found at the end of this chapter.

Fig. 7-44 shows the method of determining the reference points of a working diagram for a positive a and Fig. 7-45 for a negative a. The method of laying out a Working Diagram from Fig. 7-44 and the Connection Tables will be explained by an example. Connection Table 7-30 for 96 slots, 14 poles and spp = 2 2/7 will be used. The Table shows that a = + 2, and that the back pitch = front pitch = 7 slot pitches. The starts are all upper or top conductors; the ends are lower or bottom conductors. Using Fig. 7-44, $A1_1$ lies in upper slot 1 and connects with lower slot 1 + back pitch = 1 + 7 = 8. The end of a coil series of phase B is in slot (1 + number of slots) - front pitch = (1 + 96) - 7 = 90. From the Connection Table, this is found to be the lower lead $B1_4$. This fixes the position of the reference points.

Starting with upper conductor $A1_1$ in slot 1 and progressing clockwise, the Table designates the starts of the parts as follows:

$A1_1 = 1$, $A2_1 = 8$, $C1_1 = 17$, $C2_1 = 24$, $B1_1 = 33$,
$B2_1 = 40$, $A1_3 = 49$, $A2_3 = 56$, etc.

The number of clips or coils between $A1_1 = 1$ and $A2_1 = 8$ is 7 - 1 = 6. Similarly, between $A2_1 = 8$ and $C1_1 = 17$, there are 9 - 1 = 8 clips; between $C1_1$ and $C2_1$, 7 - 1 = 6 clips, etc. Starting

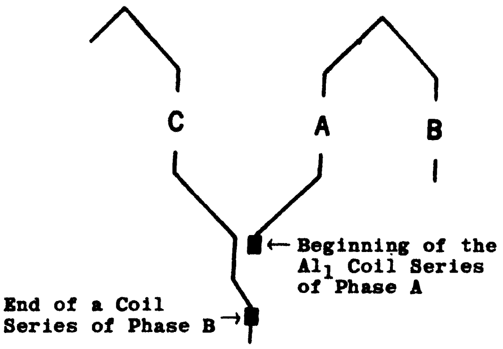

C
A
B
Beginning of the $A1_1$ Coil Series of Phase A
End of a Coil Series of Phase B

Fig. 7-44. General Working Diagram for determining the reference points, i.e., the start of a coil series of phase A, and the end of a coil series of phase B, when the sign of a is positive.

A = Top of slot 1

B = Bottom of slot (1 + back pitch)

C = Bottom of slot (1 + number of slots - front pitch.) For the designation of the corresponding end of the series, see connection table.

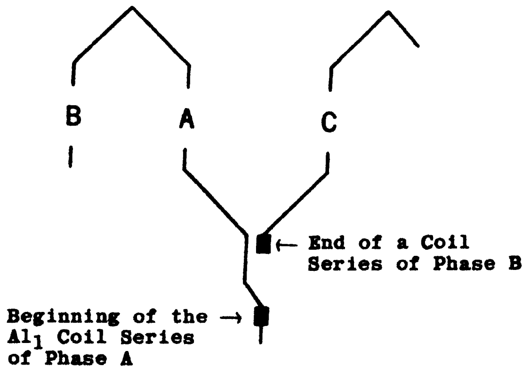

B
A
C
End of a Coil Series of Phase B
Beginning of the $A1_1$ Coil Series of Phase A

Fig. 7-45. General Working Diagram for determining the reference points, i.e., the start of a coil series of phase A, and the end of a coil series of phase B, when the sign of a is negative.

A = Bottom of slot 1

B = Top of slot (1 + number of slots - back pitch).

C = Top of slot (1 + front pitch). For the designation of the corresponding end of the series, see connection table.

now with $B1_4 = 90$, and again progressing clockwise, $B1_4 = 90$, $B2_4 = 1$, $A1_2 = 10$, $A2_2 = 17$, $C1_2 = 26$, $C2_2 = 33$, etc. Between $B1_4 = 90$ and $B2_4 = 1$ there are 96 - 90 = 6 coils or clips; between $\beta 2_4$ and $A1_2$ there are 9 - 1 = 8 coils or clips. This agrees with the number of coils found between these same points using the starts of the winding parts. The Working Diagram is shown in Fig. 7-30, and a fully developed Winding Diagram is shown in Fig. 7-30a. Working Diagrams are given for slot and pole combinations shown in Table 7-43. In this Table 7-1, 7-2, etc., indicate the Figures which represent the corresponding Working Diagrams.

Fully developed Winding Diagrams are also given for the following cases:

Fig. 7-4a
96 slots, 10 poles, spp = 3 1/5 $a = -1$ d = odd

Fig. 7-6a
90 slots, 14 poles, spp = 2 1/7 $a = +1$ d = odd

Fig. 7-17a
54 slots, 8 poles, spp = 2 1/4 $a = -1$ d = even P = odd

Fig. 7-25a
72 slots, 10 poles, spp = 2 2/5 $a = -2$ d = odd P = even

Fig. 7-30a
96 slots, 14 poles, spp = 2 2/7 $a = +2$ d = odd P = odd

Fig. 7-38a
63 slots, 8 poles, spp = 2 5/8 $a = +2$ d = even P = odd

Fig. 7-43
102 slots, 14 poles, spp = 2 3/7 $a = +3$ d = odd P = odd

The significance of values of a, d, and P is explained in Arts. 7-4 and 7-11.

7-4. Winding Pitch, Back Pitch, and Front Pitch. Number of Repeatable Parts. General Rules.

The winding pitch of the balanced fractional-slot wave windings is fixed by the fraction of spp just as the coil grouping is fixed by this fraction (see Art. 4-12). If spp is written, as in Art. 4-5, spp = $I \frac{n}{d}$ where I is the integral part of spp, and $\frac{n}{d}$ its fraction, then, for $I = 0$, the winding pitch is equal to $\frac{(6n + a)}{d}$. a is the smallest integer which makes the fraction $\frac{(6n + a)}{d}$ an integer. a can be positive as well as negative. For example, when $\frac{n}{d} = \frac{1}{7}$, the smallest value of a which makes the fraction $\frac{(6 \times 1 + a)}{7}$ an integer is $a = +1$; or, when $\frac{n}{d} = \frac{3}{8}$, the smallest value of a which makes the fraction $\frac{(6 \times 3 + a)}{8}$ an integer is $a = -2$.

The value and sign of a are of great importance in the layout of the winding. When the same absolute value of a makes the fraction $\frac{(6n + a)}{d}$ an integer, choose the sign which makes this fraction even. For example, when $\frac{n}{d} = 3/4$, the smallest absolute value of a which makes $\frac{(6 \times 3 + a)}{4}$ an integer is 2. The sign can be plus or minus, yielding for the fraction 5 and 4 respectively. The minus sign is to be chosen.

$\frac{(6n + a)}{d}$ is the winding pitch for $I = 0$. For I not equal to zero.

$$\text{winding pitch} = 6I + \frac{(6n + a)}{d} \qquad (7\text{-}1)$$

The value and sign of a are independent of the magnitude of I. Table 7-44 gives the values of the fraction $\frac{(6n + a)}{d}$ as well as the corresponding values and signs of a for different fractions $\frac{n}{d}$. The winding pitch is found by adding 6I to the fraction $\frac{(6n + a)}{d}$. For example, for spp = 2 1/7, Table 7-44 shows the value of the fraction to be equal to 1. The winding pitch is, therefore, 6 x 2 + 1 = 13. When spp = 2 2/7, Table 7-44 yields for the fraction $\frac{(6n + a)}{d}$ the value 2, and the winding pitch is then 6 x 2 + 2 = 14.

When the winding pitch is even, back pitch and front pitch are each made equal to half of the winding pitch. When the winding pitch is odd, the back pitch is made equal to (winding pitch - 1)/2 and the front pitch is then equal to (back pitch + 1). For example, in the case of spp = 2 1/7, the winding pitch is 13, the back pitch will be made equal to (13 - 1)/2 = 6 and the front pitch to 6 + 1 = 7; in the case of spp = 2 2/7, the winding pitch is 14, and back pitch as well as front pitch is made equal to 7.

It has been explained in Art. 4-5 that in balanced fractional-slot lap windings d poles make a repeatable part of the winding and that, therefore, there are $\left(\frac{\text{No. of poles}}{d}\right)$ repeatable parts in the winding. The same is true of the balanced fractional-slot wave windings because, as mentioned in Art. 7-1, the coil grouping is the same for both kinds of windings if spp is the same. Thus, d determines the number of poles in a repeatable part of the winding. For example, in a 28-pole winding with spp = 2 1/7, 7 poles make a repeatable part of the winding and there are 28/7 = 4 repeatable parts in the winding.

Spp can also be written in the form spp = $\frac{N}{d}$ where N and d have no common devisor. If, for example, spp = 2 2/7, N is equal to 16. N is always larger than d while n is always smaller than d. Note that N = spp x d is the number of slots per phase in d poles, i.e., the number of slots per phase in one repeatable part of the winding. 3N is, therefore, the total number of slots in one repeatable winding part.

For the laying out of the winding, it is necessary to determine the quantity

$$D = \frac{3N \times P + 1}{d} \qquad (7-2)$$

in such a manner that P is the smallest positive integer which makes D an integer, and to set up the series

$$1, \quad 1 + D, \quad 1 + 2D, \quad 1 + 3D, \ . \ . \ . \ \text{etc.} \qquad (7-3)$$

If, while setting up the series, a term becomes larger than the total number of slots per repeatable winding part, i.e., 3N, this quantity is to be subtracted from the term. The physical meaning of the quantity D and of the D-series is explained in Appendix 1.

Consider, for example, the winding with spp = 2 1/7 = 15/7. For this case N = 15, 3N = 45, d = 7, and D = (45 x P + 1)/7 = 13 with P = 2. The D-series becomes

1, 1 + 13 = 14, 14 + 13 = 27, 27 + 13 = 40, 40 + 13 - 45 = 8 . . ..

The winding pitch of this winding has been determined above to be 13. An examination of the D-series shows that it follows the series.

1, 1 + (winding pitch), 1 + (2 x winding pitch),
1 + (3 x winding pitch) . . .

The winding pitch is the distance between 2 consecutive upper or lower conductors of the wave winding (see Art. 6-1). In the example, the winding pitch is 13 and the back pitch is 6. This means that if the phase starts with upper conductor 1, this conductor is to be connected with lower conductor 1 + 6 = 7, and this latter conductor with upper conductor 1 + 13 = 14. The next upper conductor which follows in the wave is then 14 + 13 = 27, the next 27 + 13 = 40, the next 40 + 13 - 45 = 8, and so on, exactly as the numbers follow each other in the D-series; the D-series determines the sequence of conductors of the same layer to be connected in the process of winding.

Consider another example of a winding with spp = 2 1/5 = $\frac{11}{5}$. Table 7-44 shows that for this winding the fraction $\frac{(6n + a)}{d}$ is 1 and, therefore, the winding pitch, according to Eq. 7-1, is 6 x 2 + 1 = 13. The back pitch will be made equal to (13-1)/2 = 6 and the front pitch to 6 + 1 = 7. For this winding, N = 11, 3N = 33, and d = 5. Hence,

$$D = \frac{33 \times P + 1}{5} = 20 \quad \text{with } P = 3$$

and the D-series is

1, 1 + 20 = 21, 21 + 20 - 33 = 8, 8 + 20 = 28,
28 + 20 - 33 = 15 . . .

Examining the D-series, it follows from right to left,

15, 15 + 13 = 28, 28 + 13 - 33 = 8, 8 + 13 = 21,
21 + 13 - 33 = 1 . . .

Since the winding pitch is 13; again, the D-series determines the sequence of conductors of the same layer to be connected in the process of winding.

In the first example of spp = 2 1/7, a is equal to +1, and the D-series prescribes clockwise connection of conductors. In the second example of spp = 2 1/5, a is equal to -1 and the D-series prescribes counter-clockwise connection of conductors. In general, a positive a means clockwise winding, and a negative a means counter-clockwise winding. Since left-hand coils are assumed, start the winding in an upper conductor and wind clockwise when a is positive, and start the winding in a lower conductor and wind counter-clockwise when a is negative.

Consider now a winding for which a = + 2. Such a winding is, for example, one with spp = 2 2/7 = $\frac{16}{7}$ (see Table 7-44). For this winding, N = 16, 3N = 48, d = 7. The fraction $\frac{6n + a}{d}$ = 2 with a = + 2, the winding pitch is 6 x 2 + 2 = 14 (see Eq. 7-1), and the back pitch = front pitch = 14/2 = 7. From Eq. 7-2.

$$D = \frac{48 \times P + 1}{7} = 7 \quad \text{with } P = 1$$

and the D-series is

1, 1 + 7 = 8, 8 + 7 = 15, 15 + 7 = 22, 22 + 7 = 29,
29 + 7 = 36, 36 + 7 = 43, 43 + 7 - 48 = 2 . . .

Comparing this series with the winding-pitch series

1, 1 + (winding pitch), 1 + (2 x winding pitch),
1 + (3 x winding pitch) . . .

it is found that alternate figures of the D-series instead of consecutive figures of it follow the winding-pitch series. This means that the winding is to be wound in 2 consecutive waves, one with the upper (or lower) conductors

1 15 29 43 . . .

the other with the upper (or lower) conductors

8 22 36 36 + 14 = 50 - 48 = 2 . . .

These waves cannot be connected in parallel; they must be connected in series.

While the winding with a = 1 has $\frac{\text{(No. of poles)}}{d}$ winding parts in each phase, the winding with a = 2 has twice as many winding parts per phase which in pairs must be connected in series. Instead of connecting the parts in series, it is possible to make up 2 separate windings and connect them in series. This is explained in detail in Art. 7-10.

A winding with a = ± 2 can be considered as one consisting of 2 interlaced windings. This can be seen from the D-series which these windings follow.

The 2 series, 1, 15, 29, 43, . . . and 8, 22, 36, 2 . . . increase by the winding pitch from the left to the right, i.e., the winding is to be wound clockwise starting with an upper conductor. This is due to the fact that the sign of a is positive. A winding with a = - 2 is to be wound counter-clockwise starting with a lower conductor.

In general, the magnitude of a determines the number of winding parts per phase. A winding with a = ± 2, ± 3 . . . has twice, 3 times . . . as many winding parts per phase as the winding with a = ± 1. The sign of a determines whether the winding goes clockwise or counter-clockwise.

The general method described in this article will be demonstrated by 5 examples with a = +1, a = - 1, a = ± 2, and N even, and a = - 2 and N odd. (see Arts. 7-9 to 7-11).

7-5. Maximum Possible Number of Parallel Circuits. The maximum possible number of parallel paths is equal to $\frac{\text{(No. of poles)}}{d}$

since this is the number of repeatable parts of the winding. If a smaller number of parallel paths than the maximum possible is desirable, the latter must be divisible by the number of parallel paths chosen. The maximum possible number of parallel paths is independent of the value of a. When a is larger than 1, there are a times as many winding parts as in the case a = 1. However, a winding parts must always be connected in series when a is larger than 1; this limits the maximum possible number of parallel paths to the same value as it is in the case a = 1.

7-6. Polarities of the Starts and Ends of the Winding Parts. In order to connect the parts of each phase in series or parallel, the polarities of their starts and ends must be known. It has been mentioned in Art. 7-4 that a winding with a larger than 1 can be considered as one consisting of a interlaced separate windings each having (No. of poles/d) repeatable parts. The polarities of the starts of 2 consecutive parts of the same winding are determined by the denominator d of spp; if d is odd, the polarities are opposite; if d is even, the polarities are the same. This rule fixes the polarities of all parts of any one of the interlaced windings, if the polarity of the start of the first part is assumed. This rule applies to all 3 phases. It covers entirely the case a = ± 1.

In the case a = ± 2, the polarities of the starts of the first parts of the 2 windings are determined by the factor P (see Eq. 7-2), which determines the magnitude of D; if P is odd, the polarities are opposite for all 3 phases; if P is even, the polarities are the same for phase A and opposite for phases C and B. This rule and the first one fix for a = 1 and a = 2 the polarities of all starts of the winding with respect to the polarity of the start of the first winding, i.e., with respect to the polarity of coil side 1, which can be assumed arbitrarily.

The 2 rules refer to the starts. The end of each part has a sign opposite to that of the start of the part.

In general, in order to check the polarity of a coil side, divide the number of the coil side minus 1 by the number of slots per pole. The quotient is either a fraction which lies between 2 consecutive digits or an integer. If the polarity of slot 1 is assumed to be plus, and the quotient lies between two consecutive digits, then the slot under consideration has the polarity plus when the smaller digit is even, and the polarity minus when the smaller digit is odd. If the quotient is an integer, the slot under consideration has the polarity plus when the integer is even, and has the polarity minus when the integer is odd (the integer 0 is to be considered as even). This method of checking the polarity can be applied also to the case $a > 2$. The polarity of the beginning of a phase can be assumed arbitrarily. If this arbitrarily assumed polarity is opposite to that yielded by the polarity rule given above, the polarities of all other beginnings of this phase are to be changed.

The polarity rules given above are demonstrated by examples in Art. 7-9 to 7-13.

7-7. Beginnings of Phases. As in the case of the integral-slot and (integer + 1/2)-slot wave windings, the beginnings of the phases are placed, if possible, at 3 points having equal distances from each other. The beginning of phase A is usually conductor 1. Equal mechanical spacing of the beginnings exists when the beginnings of phase B is conductor $(1 + S/3)$ and that of phase C is conductor $(1 + 2S/3)$, or vice versa. After the starts of all parts of phase C and phase B have been determined (see Arts. 7-9 to 7-11), 2 starts, one in phase C and the other in phase B, have to be found which are equal to or as close as possible to $(1 + S/3)$ and $(1 + 2S/3)$, and the electrical angles between these beginnings must be checked. Let S_1 and S_2 be the numbers of the conductors found to be equal to or close to $(1 + S/3)$ and $(1 + 2S/3)$. Then the angle $(S_1 - 1) \times \frac{d}{N} \times 60$ must be equal or approximately equal to 120°, and the angle $(S_2 - 1) \times \frac{d}{N} \times 60$ must be equal or approximately equal to 240°, or vice versa.

If more or less equal mechanical spacing is disregarded, then A_1, B_1, and C_3 or A_1, B_3, and C_1 can be used as phase beginnings in the case d = odd number, and A_1, B_1, and C_1, in the case d = even number.

7-8. Number of Connectors Required for Series Connection of All Parts of the Phase. In the integral-slot and (integer + 1/2)-slot wave windings, only one connector (reversing jumper) is necessary for the series connection of all coils of a phase.

In the case $a = \pm 1$, $\left(\frac{(\text{No. of poles})}{d} - 1\right)$ connectors are necessary per phase for the series connection and, in the case $a = \pm 2$, $\left(\frac{(2 \times \text{No. of poles})}{d}\right) - 1$ connectors are necessary. The number of connectors is larger than in the case of the integral-slot and (integer + 1/2)-slot windings. On the other hand, as mentioned in Art. 7-1, the windings treated in this chapter have no abnormal-front pitches.

7-9. Layout of a Winding with $a = \pm 1$. Corresponding to the rules explained in Art. 7-4:

(a) Write spp = $\frac{N}{d}$ where N and d have no common divisor.

(b) Determine D from Eq. 7-2.

(c) Write the first N numbers of the D-series.

(d) Write under the N numbers determined under (c) a second, a third, etc. horizontal row, i.e., a total of $\left(\frac{\text{No. of poles}}{d}\right)$ horizontal rows, in such a manner that the numbers of each row are by 3N larger than the numbers of the foregoing row.

(e) Start with the conductor 1 and find, in the D-series determined under (d), N conductors following the winding-pitch series

1, 1 + (winding pitch), 1 + (2 x winding pitch) . . .

(f) Start with conductor (1 + 3N), which is the first conductor of the second row of the D-series, and find, in the D-series, N conductors which follow the series

(1 + 3N), (1 + 3N) + (winding pitch),
(1 + 3N) + (2 x winding pitch) . . .

(g) Start with conductor (1 + 6N), which is the first conductor of the third row of the D-series, and find, in the D-series, N conductors which follow the series

(1 + 6N), (1 + 6N) + (winding pitch),
(1 + 6N) + (2 x winding pitch) . . .

Continue in the same manner until $\left(\frac{\text{No. of poles})}{d}\right)$ waves with N conductors in each have been set up.

The $\left(\frac{\text{No. of poles}}{d}\right)$ waves, each following the winding-pitch series and determined in this way, represent the repeatable parts of phase A. These parts can be connected in parallel if desirable.

Designating the starts of the repeatable parts of phase A by A_1, A_3, A_5, ... and their ends by A_2, A_4, A_6, ..., respectively, then A_1 is conductor 1, A_3 is conductor $(1 + 3N)$, A_5 is conductor $(1 + 6N)$, and so forth, or

$$\begin{aligned} A_1 &= 1 \\ A_3 &= 1 + 3N \\ A_5 &= 1 + 6N \\ &\cdots\cdots\cdots \end{aligned} \tag{7-3}$$

It is true of phase C that

$$C_1 = 1 + ND \tag{7-4}$$

since this is the first number of the D-series which follows the N numbers of this series assigned to phase A under (c). Furthermore,

$$\begin{aligned} C_3 &= C_1 + 3N \\ C_5 &= C_1 + 6N \\ &\cdots\cdots\cdots \end{aligned} \tag{7-4}$$

It follows in the same manner for phase B:

$$\begin{aligned} B_1 &= 1 + 2ND \\ B_3 &= B_1 + 3N \\ B_5 &= B_1 + 6N \\ &\cdots\cdots\cdots \end{aligned} \tag{7-5}$$

Note that C_1 and B_1 must be smaller than 3N. If $(1 + ND)$ or $(1 + 2ND)$ is larger than 3 N, then subtract 3N or 6N or 9N, etc. until the number is smaller than 3N. Once the starts C_1, C_3 . . . B_1, B_3 . . . are given, the repeatable parts of phase C and B can be determined by adding the winding pitch (N-1) times in the case $a = +1$ and subtracting the winding pitch (N-1) times in the case $a = -1$. In the case $a = +1$, if any of the figures becomes larger than the number of slots S, then S is to be subtracted. On the other hand, in the case of $a = -1$, if any of the figures becomes negative, S is to be added.

a = + 1

The conductors determined above are upper conductors. The winding progresses cw. All repeatable parts start in upper conductors and end in lower conductors. The number of repeatable parts per phase is $\frac{\text{(No. of poles)}}{d}$. The ends A_2, A_4 ... C_2, C_4 ... B_2, B_4 ... are lower conductors and lie in slots equal to:

$$\text{Start} + \left[(N-1) \times \text{winding pitch} + \text{back pitch}\right] \qquad (7\text{-}6)$$

For example, $A_2 = A_1 + [(N-1) \times \text{winding pitch} + \text{back pitch}]$. A_2, A_4 ... C_2, C_4 ... B_2, B_4 ... must be smaller than S, otherwise subtract S or 2S, etc.

a = - 1

The conductors determined above are lower conductors. The winding progresses ccw. All repeatable parts start in lower conductors and end in upper conductors. The number of repeatable parts per phase is $\frac{\text{(No. of poles)}}{d}$. The ends A_2, A_4 ... C_2, C_4 ... B_2, B_4 ... are upper conductors and lie in slots equal to:

$$\text{Start} + \left[S - (N-1) \times \text{winding pitch} - \text{back pitch}\right] \qquad (7\text{-}7)$$

For example, $A_2 = A_1 + [S - (N-1) \times \text{winding pitch} - \text{back pitch}]$. A_2, A_4 ... C_2, C_4 ... B_2, B_4 ... must be smaller than S and positive. If larger than S, subtract S, if negative, add S.

Example for a = + 1.

A 28-pole winding in 180 slots with 2 conductors per slot will be considered. From the Master Table 3-5, spp = 2 1/7 = $\frac{15}{7}$. Thus, N = 15, 3N = 45, d = 7, n = 1. From Table 7-44 for $\frac{n}{d} = \frac{1}{7}$, $\frac{(6n + a)}{d} = 1$ with a = + 1. Therefore, the winding pitch = 12 + 1 = 13, the back pitch = (13-1)/2 = 6, the front pitch = 6 + 1 = 7. The winding progresses clockwise with all starts in upper conductors. From Eq. (7-2)

$$D = \frac{45 \times P + 1}{7} = 13 \quad \text{with } P = 2$$

There are $\frac{\text{(No. of poles)}}{d} = \frac{28}{7} = 4$ repeatable parts in each phase. The rules (c) and (d) yield for the upper conductors of phase A:

$$\left.\begin{array}{rrrrrrrrrrrrrrr}
1 & 14 & 27 & 40 & 8 & 21 & 34 & 2 & 15 & 28 & 41 & 9 & 22 & 35 & 3 \\
46 & 59 & 72 & 85 & 53 & 66 & 79 & 47 & 60 & 73 & 86 & 54 & 67 & 80 & 48 \\
91 & 104 & 117 & 130 & 98 & 111 & 124 & 92 & 105 & 118 & 131 & 99 & 112 & 125 & 93 \\
136 & 149 & 162 & 175 & 143 & 156 & 169 & 137 & 150 & 163 & 176 & 144 & 157 & 170 & 138
\end{array}\right\} \text{D-series}$$

Applying rules (e), (f), and (g), the winding-pitch series are:

1	14	27	40	53	66	79	92	105	118	131	144	157	170	3	= 1st repeatable part
46	59	72	85	98	111	124	137	150	163	176	9	22	35	48	= 2nd repeatable part
91	104	117	130	143	156	169	2	15	28	41	54	67	80	93	= 3rd repeatable part
136	149	162	175	8	21	34	47	60	73	86	99	112	125	138	= 4th repeatable part

The starts of the 4 repeatable parts of phase A lie in the slots 1, 46, 91, and 136. This is in accordance with Eq. 7-3 which yields $A_1 = 1$, $A_3 = 1 + 45 = 46$, $A_5 = 1 + 90 = 91$ and $A_7 = 1 + 9 \times 15 = 136$. It follows from this that the calculation of the D-series can be omitted, and Eq. 7-3 for the starts of the repeatable parts used instead. Applying the winding pitch series to the starts, the chart for the repeatable parts will be obtained.

The ends of the 4 parts lie in the lower conductors (Eq. 7-6):

$$A_2 = 1 + (15-1) \times 13 + 6 = 1 + 188 = 189 - 180 = 9$$
$$A_4 = 46 + 188 - 180 = 54$$
$$A_5 = 91 + 188 - 180 = 99$$
$$A_7 = 136 + 188 - 180 = 144$$

To lay out the first part of phase A, start with upper conductor 1, connect it with the lower conductor (1 + back pitch) = 1 + 6 = 7, connect this conductor with the second upper conductor of the chart, 14, and so forth, ending with lower conductor 3 + 6 = 9 = A_2.

Since d = 7 is odd, the polarities of the starts of 2 consecutive parts of the same phase are opposite. The same applies to the polarity of the ends. It follows from Fig. 7-46, which shows the polarities of the starts and ends, that, for the series connection of phase A, connect A_4 with A_2, A_8 with A_6, and A_3 with A_5; A_1 and A_7 are the leads. If 4 parallel circuits are desirable, connect A_1, A_4, A_5, and A_8 to one lead, and A_2, A_3, A_6, and A_7 to the other lead. If 2 parallel circuits are desirable, connect A_4 with A_2, A_5 with A_7, A_1 with A_8, and A_3 with A_6. $A_1 \rightarrow A_8$ and $A_3 \rightarrow A_6$ are the leads. (See Connection Table 7-7 and Working Diagram Fig. 7-7.)

↑ A_1	A_2 ↓	↑ C_1	C_2 ↓	↑ B_1	B_2 ↓
↓ A_3	A_4 ↑	↓ C_3	C_4 ↑	↓ B_3	B_4 ↑
↑ A_5	A_6 ↓	↑ C_5	C_6 ↓	↑ B_5	B_6 ↓
↓ A_7	A_8 ↑	↓ C_7	C_8 ↑	↓ B_7	B_8 ↑

($a = \pm 1$ d = odd)

Subscripts 1, 3, 5, 7, etc., denote the beginnings of the winding parts.

Subscripts 2, 4, 6, 8, etc., denote the ends of the winding parts.

Fig. 7-46. Polarities of the starts and ends of all phases of a winding with $a = \pm 1$ and d = odd.

The starts of the 4 parts of phase C lie in the upper conductors (see Eq. 7-4).

$$C_1 = 1 + 15 \times 13 = 196 - 12 \times 15 = 16$$
$$C_3 = 16 + 45 = 61$$
$$C_5 = 16 + 90 = 106$$
$$C_7 = 16 + 135 = 151$$

and the ends lie in the lower conductors (see Eq. 7-6):

$$C_2 = 16 + (15 - 1) \times 13 + 6 = 16 + 188 - 180 = 24$$
$$C_4 = 61 + 188 - 180 = 69$$
$$C_6 = 106 + 188 - 180 = 114$$
$$C_8 = 151 + 188 - 180 = 159$$

Eqs. 7-5 and 7-6 yield for phase B

$$B_1 = 1 + 2 \times 15 \times 13 - 24 \times 15 = 31$$
$$B_2 = 31 + (15-1) \times 13 + 6 - 180 = 39$$
$$B_3 = 31 + 45 = 76$$
$$B_4 = 76 + 188 - 180 = 84$$
$$B_5 = 31 + 90 = 121$$
$$B_6 = 121 + 188 - 180 = 129$$
$$B_7 = 31 + 135 = 166$$
$$B_8 = 166 + 188 - 180 = 174$$

For equal mechanical spacing of the beginnings of the phases, phase B should start in slot $1 + S/3$, and phase C in slot $1 + 2 \times (S/3)$, or vice versa, i.e., in this case in slot $(1 + \frac{180}{3}) = 61$ and $(1 + 2 \times \frac{180}{3}) = 121$. C_3 lies in slot 61, and B_5 lies in slot 121. Thus B_5 can be taken as the beginning of phase B, and C_3 as the beginning of phase C. Checking the angles between the beginnings of the 3 phases, $(B_5 - 1) \times \frac{d}{N} \times 60 = (121 - 1) \times \frac{7}{15} \times 60 = 3360 - 9 \times 360 = 120^o$, and $(C_3 - 1) \times \frac{d}{N} \times 60 = (61 - 1) \times \frac{7}{15} \times 60 = 1680 - 1440 = 240^o$, as it should be. For series, as well as for parallel connection, B_5 and C_3 should be used as the leads.

Example with $a = -1$.

A 10-pole winding in 66 slots with 2 conductors per slot will be considered. From the Master Table 3-5, spp = 2 1/5 = $\frac{11}{5}$. Thus $N = 11$, $3N = 33$, $d = 5$, $n = 1$. From Table 7-44 for $\frac{n}{d} = \frac{1}{5}$, $\frac{6n + a}{d} = 1$ with $a = -1$. Therefore, the winding pitch $= 12 + 1 = 13$, the back pitch $= \frac{13-1}{2} = 6$, and the front pitch $= 6 + 1 = 7$. The winding progresses counter-clockwise with all starts in the lower conductors. From Eq. 7-2.

$$D = \frac{33 \times P + 1}{5} = 20 \text{ with } P = 3$$

There are $10/5 = 2 = \frac{(\text{No. of poles})}{d}$ repeatable parts in each phase. The rules (c) and (d) yield for the lower conductors of phase A

$$\left.\begin{array}{ccccccccccc} 1 & 21 & 8 & 28 & 15 & 2 & 22 & 9 & 29 & 16 & 3 \\ 34 & 54 & 41 & 61 & 48 & 35 & 55 & 42 & 62 & 49 & 36 \end{array}\right\} \text{D-series}$$

Applying rules (e), (f), and (g), the winding-pitch series are:

1 54 41 28 15 2 55 42 29 16 3 = 1st repeatable part
34 21 8 61 48 35 22 9 62 49 36 = 2nd repeatable part

The starts of the 2 parts of phase A lie in the slots 1 and 34. This is in accordance with Eq. 7-3 which yields $A_1 = 1$, and $A_3 = 1 + 33 = 34$. The ends of the 2 parts lie in the upper conductors (Eq. 7-7):

$$A_2 = A_1 + 66 - (11-1) \times 13 - 6 = 67 - 136 = -69 + 2 \times 66 = 63$$
$$A_4 = A_3 + 66 - 136 = -36 + 66 = 30$$

To make up the first part of phase A, start with the lower conductor 1, connect it with the upper conductor 1 + (S - back pitch) = 1 + (66 - 6) = 61, connect this conductor with the second lower conductor of the chart, 54. This conductor is to be connected with the upper 54 - 6 = 48, and this upper with the third lower conductor of the chart, 41, and so forth, ending with the upper conductor $3 - 6 + 66 = 63 = A_2$. The same procedure is to be followed for the remaining part of phase A, starting now with lower conductor 34.

The starts of the 2 parts of phase C and B are the lower conductors (Eq. 7-4 and 7-5):

$$C_1 = 1 + 11 \times 20 - 6 \times 33 = 23$$
$$C_3 = 23 + 33 = 56$$
$$B_1 = 1 + 2 \times 11 \times 20 - 13 \times 33 = 12$$
$$B_3 = 12 + 33 = 45$$

and the ends are the upper conductors (Eq. 7-7):

$$C_2 = C_1 + 66 - 136 = -47 + 66 = 19$$
$$C_4 = C_3 + 66 - 136 = -14 + 66 = 52$$
$$B_2 = B_1 + 66 - 136 = -58 + 66 = 8$$
$$B_4 = B_3 + 66 - 136 = -25 + 66 = 41$$

Since d = 5 is odd, the polarities of the starts of 2 consecutive parts of the same phase are opposite. It follows from the chart (Fig. 7-46) which shows the polarities of the starts and ends that, for series connection, A_2 is to be connected with A_4, C_2

with C_4, and B_2 with B_4. For 2 parallel circuits (= maximum possible number of parallel circuits), A_1 is to be connected with A_4 and A_2 with A_3, further, C_1 with C_4, C_2 with C_3, B_1 with B_4, and B_2 with B_3.

For equal mechanical spacing of the beginnings of the phases, the beginning of phase B should lie in slot $1 + \frac{S}{3} = 1 + 22 = 23$ and that of phase C in slot $1 + 2 \times (\frac{S}{3}) = 1 + 44 = 45$ or vice versa. C_1 lies in slot 23, and B_3 lies in slot 45. Thus, B_3 can be taken as the beginning of phase B, and C_1 as the beginning of phase C. This applies to the series as well as to the parallel connection. Checking the angles between the beginnings of the 3 phases, $(B_3-1) \times \frac{d}{N} \times 60 = (45-1) \times \frac{5}{11} \times 60 = 1200 - 3 \times 360 = 120^\circ$ and $(C_1-1) \times \frac{d}{N} \times 60 = (23-1 \times \frac{5}{11} \times 60 = 600 - 360 = 240^\circ$.

7-10. Layout of a Winding with a = ± 2 and N = Even Number. As explained in Art. 7-4, the winding with a = ± 2 is to be treated as 2 interlaced windings. One of them will be designated by the figure 1, the other by the figure 2, each following the letter designating the phase. Thus, A1 means the first of the interlaced windings of phase A, A2 means the second of the interlaced windings of phase A. Further $A1_1$ means the start of the first repeatable part of the first winding; $A2_1$ means the start of the first repeatable part of the second winding; $A1_3$ means the start of the second repeatable part of the first winding, and so forth.

↑ A_1	A_2 ↓	↑C_1	C_2 ↓	↑B_1	B_2 ↓
↑ A_3	A_4 ↓	↑C_3	C_4 ↓	↑B_3	B_4 ↓
↑ A_5	A_6 ↓	↑C_5	C_6 ↓	↑B_5	B_6 ↓
↑ A_7	A_8 ↓	↑C_7	B_8 ↓	↑B_7	B_8 ↓

a = ± 1 d = even

Subscripts 1, 3, 5, 7, etc., denote the beginnings of the winding parts.

Subscripts 2, 4, 6, 8, etc., denote the ends of the winding parts.

Fig. 7-47. Polarities of the starts and ends of all 3 phases of a winding with a = ± 1 and d = even

Considering the windings with $a = \pm 2$, distinction must be made between N = even and N = odd. In the first case both windings will have the same number of coils; in the second case one winding has more coils than the other. The latter case will be treated in the following Art. 7-11. In this article, only windings with $a = \pm 2$ and N = even will be considered.

In order to lay out a winding with $a = \pm 2$ corresponding to the rules explained in Art. 7-4:

(a) Write spp = $\frac{N}{d}$ where N and d have no common divisor.

(b) Determine D from Eq. 7-2.

(c) Write the first N numbers of the D-series.

(d) Write under the N numbers determined under (c) a second, a third, etc., horizontal row, i.e., a total of $\frac{(\text{No. of poles})}{d}$ horizontal rows, in such a manner that the numbers of each row are by 3N larger than the numbers of the foregoing row.

(e) Start with conductor 1 and find, in the D-series determined under (d), N/2 conductors following the winding-pitch series 1, 1 + (winding pitch), 1 + (2 x winding pitch), . . . These are conductors belonging to part (wave) 1 of the first winding of phase A, i.e., the part which starts with $A1_1$ and ends with $A1_2$.

(f) Start with conductor 1 + D, i.e., with the conductor following conductor 1,and find, in the D-series, N/2 conductors, which follow the series 1 + D, (1 + D) + (winding pitch), (1 + D) + (2 x winding pitch), . . . These are then the conductors belonging to part (wave) 1 of the second winding of phase A, i.e., the part which starts with $A2_1$ and ends with $A2_2$.

(g) Start with conductor (1 + 3N) which is the first conductor of the second row of the D-series, and find, in the D-series, N/2 conductors which follow the series (1 + 3N), (1 + 3N) + (winding pitch), (1 + 3N) + (2 x winding pitch), . . . These are the conductors belonging to part (wave) 2 of the first winding of phase A, i.e., the part which starts with $A1_3$ and ends with $A1_4$.

(h) Start with conductor (1 + 3N + D), which is the second conductor of the second row of the D-series, and find, in the

D-series, N/2 conductors which follow the series $(1 + 3N + D)$, $(1 + 3N + D) +$ (winding pitch), $(1 + 3N + D) + (2 \times$ winding pitch), . . . These are the conductors belonging to part (wave) 2 of the second winding of phase A, i.e., the part which starts with $A2_3$ and ends with $A2_4$.

Continue in the same manner, until $2 \times \frac{\text{(No. of poles)}}{d}$ parts, with N/2 conductors in each have been obtained.

The odd parts (waves) $A1_1$, $A1_3$, $A1_5$, . . . belong to the first winding of phase A; the even parts (wave) $A2_1$, $A2_3$, $A2_5$ . . . belong to the second winding of phase A. The parts of each winding can be connected in parallel, the maximum possible number of parallels being $\frac{\text{(No. of poles)}}{d}$, but both windings cannot be connected in parallel, they must be connected in series.

The starts of the 3 phases expressed in formulae are:

$$\left.\begin{aligned} A1_1 &= 1 \\ A1_3 &= 1 + 3N \\ A1_5 &= 1 + 6N \\ &\cdots\cdots \end{aligned}\right\} \quad (7\text{-}8) \qquad \left.\begin{aligned} A2_1 &= 1 + D \\ A2_3 &= A2_1 + 3N \\ A2_5 &= A2_1 + 6N \\ &\cdots\cdots \end{aligned}\right\} \quad (7\text{-}9)$$

$$\left.\begin{aligned} C1_1 &= 1 + ND \\ C1_3 &= C1_1 + 3N \\ C1_5 &= C1_1 + 6N \\ &\cdots\cdots \end{aligned}\right\} \quad (7\text{-}10) \qquad \left.\begin{aligned} C2_1 &= C1_1 + D \\ C2_3 &= C2_1 + 3N \\ C2_5 &= C2_1 + 6N \\ &\cdots\cdots \end{aligned}\right\} \quad (7\text{-}11)$$

$$\left.\begin{aligned} B1_1 &= 1 + 2ND \\ B1_3 &= B1_1 + 3N \\ B1_5 &= B1_1 + 6N \\ &\cdots\cdots \end{aligned}\right\} \quad (7\text{-}12) \qquad \left.\begin{aligned} B2_1 &= B1_1 + D \\ B2_3 &= B2_1 + 3N \\ B2_5 &= B2_1 + 6N \\ &\cdots\cdots \end{aligned}\right\} \quad (7\text{-}13)$$

Note that $C1_1$, $B1_1$, $C2_1$, and $B2_1$, must be smaller than 3N. This quantity, or 6N or 9N, etc., is to be subtracted when the formula yields a value larger than 3N.

As in the case of $a = \pm 1$, the ends of phases C and B can be found from their starts $C1_1$, $C2_1$, . . . $B1_1$, $B2_1$, . . ., by adding the winding pitch $(\frac{N}{2} - 1)$ times for the case $a = +2$, and subtracting the winding pitch $(\frac{N}{2} - 1)$ times for the case $a = -2$. If, in the case $a = +2$ any of the figures becomes larger than the number of slots S, then S is to be subtracted. On the other hand, if in the case $a = -2$ any of the figures becomes negative, S is to be added.

$a = +2$

The conductors determined above are upper conductors. The winding progresses cw. All parts start in upper conductors and end in lower conductors. The number of parts per phase is $2 \times \frac{(\text{No. of poles})}{d}$ with half of this number in each of the 2 interlaced windings. The ends $A1_2$, $A2_2$, $A1_4$, $A2_4$ . . . $C1_2$, $C2_2$, $C1_4$, $C2_4$ . . . $B1_2$, $B2_2$, $B1_4$, $B2_4$ . . . lie in slots equal to:

$$\text{Start} + \left[\frac{(N-2)}{2} \times \text{winding pitch} + \text{back pitch}\right] \qquad (7\text{-}14)$$

For example, $A2_2$ lies in lower conductor $A2_1 + \left[\frac{(N-2)}{2} \times \text{winding pitch} + \text{back pitch}\right]$. $A1_2$, $A2_2$ . . . $C1_2$, $C2_2$ . . . $B1_2$, $B2_2$ . . . must be smaller than S, otherwise subtract S or 2S, etc.

$a = -2$

The conductors determined above are lower conductors. The winding progresses ccw. All parts start in lower conductors and end in upper conductors. The number of parts per phase is $2 \times \frac{(\text{No. of poles})}{d}$ with half of this number in each of the 2 interlaced windings. The ends $A1_2$, $A2_2$, $A1_4$, $A2_4$ . . . $C1_2$, $C2_2$, $C1_4$, $C2_4$ . . . $B1_2$, $B2_2$, $B1_4$, $B2_4$ . . . lie in slots equal to:

$$\text{Start} + \left[S - \frac{(N-2)}{2} \times \text{winding pitch} - \text{back pitch}\right] \qquad (7\text{-}15)$$

For example, $A2_2$ lies in upper conductor $A2_1 + \left[S - \frac{(N-2)}{2} \times \text{winding pitch} - \text{back pitch}\right]$. $A1_2$, $A2_2$ . . . $C1_2$, $C2_2$ . . . $B1_2$, $B2_2$ . . . must be smaller than S and positive. If larger than S, subtract S; if negative, add S.

Example for a = + 2 and N = even.

A 14-pole winding in 96 slots with 2 conductors per slot will be considered. From the Master Table 3-5, spp = 2 2/7 = $\frac{16}{7}$. Thus N = 16, 3N = 48, d = 7, n = 2. From Table 7-44 for $\frac{n}{d} = \frac{2}{7}$, $\frac{(6n + a)}{d} = 2$ with $\underline{a} = + 2$. Therefore, the winding pitch = (6 x 2) + 2 = 14 (see Eq. 7-1), the back pitch = front pitch = 7. The winding progresses clockwise with all the starts in upper conductors. From Eq. 7-2

$$D = \frac{3 \times 16 \times P + 1}{7} = 7 \text{ with } P = 1$$

There are in each phase $\underline{a}$ = 2 interlaced windings, each with $\frac{(\text{No. of poles})}{d} = \frac{14}{7} = 2$ parts. The total number of parts per phase is 4.

Rules (c) and (d) yields for the upper conductors of phase A

$$\left.\begin{array}{cccccccccccccccc} 1 & 8 & 15 & 22 & 29 & 36 & 43 & 2 & 9 & 16 & 23 & 30 & 37 & 44 & 3 & 10 \\ 49 & 56 & 63 & 70 & 77 & 84 & 91 & 50 & 57 & 64 & 71 & 78 & 85 & 92 & 51 & 58 \end{array}\right\} \text{D-series}$$

Applying rules (e) to (h), the 4 parts (waves) of phase A:

1 15 29 43 57 71 85 3 = 1st part of 1st winding

8 22 36 50 64 78 92 10 = 1st part of 2nd winding

49 63 77 91 9 23 37 51 = 2nd part of 1st winding

56 70 84 2 16 30 44 58 = 2nd part of 2nd winding

In order to lay out the winding, start with upper conductor 1 and connect it with lower conductor 1 + 7 = 8; then connect this conductor with the second upper conductor of the first part of the first winding, 15, and so forth. The same is to be repeated with the other 3 parts.

The starts of both interlaced windings lie in the slots

$A1_1 = 1$ $\qquad$ $A2_1 = 8$

$A1_3 = 49$ $\qquad$ $A2_3 = 56$

This is in accordance with Eqs. 7-8 and 7-9. The ends of the 4 parts lie in the slots (Eq. 7-14).

$$A1_2 = 1 + (7 \times 14 + 7) = 1 + 105 - 96 = 10$$
$$A1_4 = 49 + 105 - 96 = 58$$
$$A2_2 = 8 + 105 - 96 = 17$$
$$A2_4 = 56 + 105 - 96 = 65$$

The polarities of the starts can be determined according to the rules given in Art. 7-6. Since d is odd, the starts of part 1 and part 2 of each of the interlaced windings have opposite signs. (For example $A1_1$ and $A1_3$ have opposite signs.) Further, the factor P which determines the magnitude of D is odd and this means that the polarities of thè starts of the first parts of both windings are opposite. (For example $A1_1$ and $A2_1$ have opposite signs). This yields Fig. 7-48 for the polarities of starts and ends of all the phases.

In general, the series connection can be accomplished in 3 different ways; the parts of each winding are connected first in series and then all windings are connected in series; or each winding is closed to a ring and then all rings opened at points

↑ $A1_1$	$A1_2$ ↓	↑ $C1_1$	$C1_2$ ↓	↑ $B1_1$	$B1_2$ ↓
↓ $A1_3$	$A1_4$ ↑	↓ $C1_3$	$C1_4$ ↑	↓ $B1_3$	$B1_4$ ↑
↑ $A1_5$	$A1_6$ ↓	↑ $C1_5$	$C1_6$ ↓	↑ $B1_5$	$B1_6$ ↓
↓ $A2_1$	$A2_2$ ↑	↓ $C2_1$	$C2_2$ ↑	↓ $B2_1$	$B2_2$ ↑
↑ $A2_3$	$A2_4$ ↓	↑ $C2_3$	$C2_4$ ↓	↑ $B2_3$	$B2_4$ ↓
↓ $A2_5$	$A2_6$ ↑	↓ $C2_5$	$C2_6$ ↑	↓ $B2_5$	$B2_6$ ↑

$a = \pm 2 \quad d = \text{odd} \quad P = \text{odd}$

Figure 1 following the letter designating a phase denotes the first of the interlaced windings.

Figure 2 following the letter designating a phase denotes the second of the interlaced windings.

Subscripts 1, 3, 5, etc., denote the beginnings of the parts of the interlaced windings.

Subscripts 2, 4, 6, etc., denote the ends of the parts of the interlaced windings.

Note that both windings cannot be connected in parallel; they must be connected in series.

Fig. 7-48. Polarities of the starts and ends of all 3 phases of a winding with $a = \pm 2$, d = odd, and P = odd

close to each other and connected in series; or a part of the first winding is connected in series with a part of the second, third, and so forth, and all these groups or parts are then connected in series.

In the example considered, the third method gives the shortest connectors. Thus, for series connection, connect $A1_2$ with $A2_2$, further $A1_4$ with $A2_4$, and $A2_1$ with $A2_3$. $A1_1$ and $A1_3$ are the leads. For 2-parallel connection, connect $A1_2$ with $A2_2$, and $A1_3$ with $A2_3$. This places the parts of both windings in series. Now connect $A1_1$ with $A1_4$, and $A2_4$ with $A2_1$. $A1_1 \rightarrow A1_4$ and $A2_4 \rightarrow A2_1$ are the leads. (See Connection Table 7-30 and Figs. 7-30 and 7-30a)

The starts and ends of phases C and B lie in the slots (Eqs. 7-10 to 7-14):

$C1_1 = 1 + 16 \times 7 = 113 - 2 \times 48 = 17$
$C1_2 = 17 + (7 \times 14 + 7) = 17 + 105 - 96 = 26$
$C1_3 = 17 + 48 = 65$
$C1_4 = 65 + 105 - 96 = 74$
$C2_1 = 17 + 7 = 24$
$C2_2 = 24 + 105 - 96 = 33$
$C2_3 = 24 + 48 = 72$
$C2_4 = 72 + 105 - 96 = 81$
$B1_1 = 1 + 2 \times 16 \times 7 - 4 \times 48 = 33$
$B1_2 = 33 + 105 - 96 = 42$
$B1_3 = 33 + 48 = 81$
$B1_4 = 81 + 105 - 96 = 90$
$B2_1 = 33 + 7 = 40$
$B2_2 = 40 + 105 - 96 = 49$
$B2_3 = 40 + 48 = 88$
$B2_4 = 88 + 105 - 192 = 1$

For equal mechanical spacing of the beginnings of the phases, phase B should start in slot $1 + \frac{S}{3} = 33$, and phase C in slot $1 + 2 \times (\frac{S}{3}) = 65$ or vice versa. $C1_3$ lies in slot 65, and $B1_1$ lies in slot 33. Thus $B1_1$ can be taken as the beginning of phase B, and $C1_3$ as the beginning of phase C. Checking the angles between the beginnings of the 3 phases $(B1_1 - 1) \times \frac{d}{N} \times 60 = 32 \times \frac{7}{16} \times 60 = 840 - 2 \times 360 = 120^{\circ}$, and $(C1_3 - 1) \times \frac{d}{N} \times 60 = 64 \times \frac{7}{16} \times 60 = 1680 - 4 \times 360 = 240^{\circ}$.

For series or parallel connection of phases B and C, the same considerations apply as to phase A, and the connections are to be made in such a manner that $A1_1$, $B1_1$, and $C1_3$ go either to the line or to the slip-rings.

Example for a = - 2 and N = even.

A 10-pole winding in 72 slots will be considered. From the Master Table 3-5, spp = 2 2/5 = $\frac{12}{5}$. Thus, N = 12, d = 5. From Table 7-44 for $\frac{n}{d} = \frac{2}{5}$, $\frac{6n + a}{d} = 2$ and a = - 2. The winding pitch is, therefore, = 6 x 2 + 2 = 14; back pitch = front pitch = 7. Since the sign of a is negative, the winding progresses counterclockwise and has all the starts in lower conductors. From Eq. 7-2

$$D = \frac{3 \times 12 \times P + 1}{5} = 29 \quad \text{with } P = 4$$

There are in each phase 2 interlaced windings, each with $\frac{(\text{No. of poles})}{d} = \frac{10}{5} = 2$ parts. The total number of parts per phase is 2 x 2 = 4.

Rules (c) and (d) yield for the lower conductors of phase A:

$$\left.\begin{array}{cccccccccccc} 1 & 30 & 23 & 16 & 9 & 2 & 31 & 24 & 17 & 10 & 3 & 32 \\ 37 & 66 & 59 & 52 & 45 & 38 & 67 & 60 & 53 & 46 & 39 & 68 \end{array}\right\} \text{D-Series}$$

Applying rules (e) to (h), the 4 parts (waves) of phase A are:

1 59 45 31 17 3 = 1st part of the 1st winding

30 16 2 60 46 32 = 1st part of the 2nd winding

37 23 9 67 53 39 = 2nd part of the 1st winding

66 52 38 24 10 68 = 2nd part of the 2nd winding

In order to lay out the winding, start with lower conductor 1 and connect it with upper conductor 72 + 1 - 7 = 66; then connect this upper conductor with the second lower conductor 66 - 7 = 59 and so forth, ending with upper conductor 72 + 3 - 7 = 68 = $A1_2$. The same is to be repeated with the other three parts. The starts of the parts of phase A lie in the slots

$$A1_1 = 1 \qquad A2_1 = 30$$
$$A1_3 = 37 \qquad A2_3 = 66$$

which is in accordance with Eqs. 7-8 and 7-9.

Applying Eq. 7-15, the ends of the four parts lie in slots:

$$A1_2 = 1 + \left[72 - \frac{12 - 2}{2} \times 14 - 7\right] = 1 + \left[- 5\right] + 72 = 68$$

(72 is added, in order to make $A1_2$ positive)

$$A1_4 = 37 + \left[- 5\right] = 32$$
$$A2_1 = 30 + \left[- 5\right] = 25$$
$$A2_4 = 66 + \left[- 5\right] = 61$$

Applying Eqs. 7-10, 7-11, and 7-15, the starts and ends of phase C are found to lie in slots:

$C1_1 = 25$ $C1_2 = 20$
$C1_3 = 61$ $C1_4 = 56$
$C2_1 = 18$ $C2_2 = 13$
$C2_3 = 54$ $C2_4 = 49$

and applying Eqs. 7-12, 7-13, and 7-15, the starts and ends of phase B are found to lie in slots:

$B1_1 = 13$ $B1_2 = 8$
$B1_3 = 49$ $B1_4 = 44$
$B2_1 = 6$ $B2_2 = 1$
$B2_3 = 42$ $B2_4 = 37$

Since d is odd, the starts of part 1 and part 2 of each of the interlaced windings have opposite signs ($A1_1$ and $A1_3$ have opposite signs, as do also $C1_1$ and $C1_3$ and $B1_1$ and $B1_3$). Further, the factor P which determines the magnitude of D is even, and this means that the polarities of the starts of the first parts of the interlaced windings are the same for phase A ($A1_1$ has the same polarity as $A2_1$), but are opposite for phases C and B ($C1_1$ is opposite to $C2_1$ and $B1_1$ is opposite to $B2_1$). This is shown in Fig. 7-49.

The polarities of the starts of the parts of the 2 interlaced windings can also be checked by use of the general formula given in Art. 7-6. The number of slots per pole, for the winding described, is $\frac{72}{10} = 7\ 1/5$. Assume the polarity of $A1_1$ to be plus = (↑). Then the polarity of $A2_1$ which lies in slot 30 will be determined by the quotient of $\frac{30 - 1}{7\ 1/5}$ which lies between 4 and 5. Since the smaller digit 4 is even, the polarity is the same as $A1_1$. Similarly, the polarity of $A1_3$ which lies in slot 37 is determined by the quotient $\frac{37 - 1}{7\ 1/5} = 5$. Since 5 is odd, the polarity is opposite to $A1_1$. In like manner, the polarities of the remaining parts are obtained. Tabulated below are the slots in which the starts of all parts lie, the digits between which lies the quotient of $\frac{\text{No. of slot} - 1}{\text{No. of slots per pole}}$, and the polarity obtained.

Slot in Which the Start Lies	Quotient Lies Between	Polarity with Respect to the Assumed Polarity of $A1_1$
$A1_1 = 1$	-	↑
$A2_1 = 30$	4 to 5	↑
$A1_3 = 37$	5	↓
$A2_3 = 66$	9 to 10	↓
$C1_1 = 25$	3 to 4	↓
$C2_1 = 18$	2 to 3	↑
$C1_3 = 61$	8 to 9	↑
$C2_3 = 54$	7 to 8	↓
$B1_1 = 13$	1 to 2	↓
$B2_1 = 6$	0 to 1	↑
$B1_3 = 49$	6 to 7	↑
$B2_3 = 42$	5 to 6	↓

In the Connection Table (7-25), the polarities of the starts $C1_1$ and $B1_1$ have been assumed to be the same as $A1_1$. Therefore, to make the above-calculated polarities of phases C and B conform to the Table, the polarities of all the starts of these phases are to be reversed. This yields

$A1_1 = \uparrow$	$C1_1 = \uparrow$	$B1_1 = \uparrow$
$A2_1 = \uparrow$	$C2_1 = \downarrow$	$B2_1 = \downarrow$
$A1_3 = \downarrow$	$C1_3 = \downarrow$	$B1_3 = \downarrow$
$A2_3 = \downarrow$	$C2_3 = \uparrow$	$B2_3 = \uparrow$

This is in agreement with the results shown in Connection Table 7-25 and with the general polarity Fig. 7-49 which covers the case for $a \doteq \pm 2$, d = odd, and P = even.

The arbitrary assumption that the polarities of $C1_1$ and $B1_1$ are the same as that of $A1_1$ and the reversing of all other polarities of these phases do not affect the connection of the parts, since the relative polarities of the parts remain the same. The Working Diagram for this winding is shown in Fig. 7-25 and a fully developed Winding Diagram is shown in Fig. 7-25a.

↑$A1_1$	$A1_2$↓	↑$C1_1$	$C1_2$↓	↑$B1_1$	$B1_2$↓
↓$A1_3$	$A1_4$↑	↓$C1_3$	$C1_4$↑	↓$B1_3$	$B1_4$↑
↑$A1_5$	$A1_6$↓	↑$C1_5$	$C1_6$↓	↑$B1_5$	$B1_6$↓
↑$A2_1$	$A2_2$↓	↓$C2_1$	$C2_2$↑	↓$B2_1$	$B2_2$↑
↓$A2_3$	$A2_4$↑	↑$C2_3$	$C2_4$↓	↑$B2_3$	$B2_4$↓
↑$A2_5$	$A2_6$↓	↓$C2_5$	$C2_6$↑	↓$B2_5$	$B2_6$↑

$a = \pm 2$ $d =$ odd $P =$ even

Figure 1 following the letter designating a phase denotes the first of the interlaced windings.

Figure 2 following the letter designating a phase denotes the second of the interlaced windings.

Subscripts 1, 3, 5, etc. denote the beginnings of the parts of the interlaced windings.

Subscripts 2, 4, 6, etc. denote the ends of the parts of the interlaced windings.

Note that both windings cannot be connected in parallel; they must be connected by series.

Fig. 7-49. Polarities of the starts and ends of all 3 phases of a winding with $a = \pm 2$, $d =$ odd, and $P =$ even

7-11. Layout of a Winding with $a = \pm 2$ and $N =$ Odd Number.

It has been already mentioned that, in the case of $a = \pm 2$ and $N =$ odd number, both windings have a different number of coils. The rules (a) to (h) given in Art. 7-10 for $a = \pm 2$ and $N =$ even, also apply here but with some changes. Since all the D-series determined under (c) and (d) here have an odd number of conductors, the parts of the first winding will have $\frac{N+1}{2}$ conductors and the parts of the second winding will have $\frac{N-1}{2}$ conductors. For this reason, under rules (e) and (g) which refer to the first winding, $\frac{N+1}{2}$ conductors following the winding-pitch series are to be determined and, under rules (f) and (h) which refer to the second winding, $\frac{N-1}{2}$ conductors following the winding-pitch series are to be determined.

The rules on parallel and series connections given in Art. 7-10 and Eqs. 7-8 to 7-13 for the starts of the parts of both windings also apply here. However, Eqs. 7-14 and 7-15 for the ends must be adapted to the different numbers of coils in both windings.

$a = +2$

The ends $A1_2$, $A1_4$ ... $C1_2$, $C1_4$ ... $B1_2$, $B1_4$ ... lie in slots equal to:

$$\text{Start} + \left[\left(\frac{N-1}{2}\right) \times \text{winding pitch} + \text{back pitch}\right] \tag{7-16}$$

and the ends $A2_2$, $A2_4$ ... $C2_2$, $C2_4$ ... $B2_2$, $B2_4$ ... lie in slots equal to:

$$\text{Start} + \left[\left(\frac{N-3}{2}\right) \times \text{winding pitch} + \text{back pitch}\right] \tag{7-17}$$

All ends must be smaller than S, otherwise subtract S or 2S, etc.

$a = -2$

The ends $A1_2$, $A1_4$ ... $C1_2$, $C1_4$ ... $B1_2$, $B1_4$ ... lie in slots equal to:

$$\text{Start} + \left[S - \left(\frac{N-1}{2}\right) \times \text{winding pitch} - \text{back pitch}\right] \tag{7-18}$$

and the ends $A2_2$, $A2_4$ ... $C2_2$, $C2_4$ ... $B2_2$, $B2_4$ ... lie in slots equal to:

$$\text{Start} + \left[S - \left(\frac{N-3}{2}\right) \times \text{winding pitch} - \text{back pitch}\right] \tag{7-19}$$

All ends must be smaller than S and positive. If larger than S, subtract S; if negative, add S.

Example for a = - 2 and N = odd.

A 24-pole winding in 171 slots with 2 conductors per slot will be considered. From the Master Table 3-5, spp = $2\frac{3}{8} = \frac{19}{8}$. Thus, N = 19, 3N = 57, d = 8, n = 3. From Table 7-44 for $\frac{n}{d} = \frac{3}{8}$, $\frac{(6n + a)}{d} = 2$ with $a = -2$. Therefore, the winding pitch = (6 x 2) + 2 = 14, the back pitch = the front pitch = 7. The winding progresses counter-clockwise with all starts lying in lower conductors. From Eq. 7-2

$$D = \frac{57 \times P + 1}{8} = 50 \text{ with } P = 7$$

There are in each phase, a = 2 interlaced windings, each with $\left(\frac{\text{No. of poles}}{d}\right) = \frac{24}{8} = 3$ parts. The total number of parts per phase is 6. The 3 parts of the first winding have $\left(\frac{N+1}{2}\right) = 10$ lower and 10 upper conductors each; the 3 parts of the second winding have $\left(\frac{N-1}{2}\right) = 9$ lower and 9 upper conductors each.

Rules (c) and (d) of Art. 7-10 yield for the lower conductors of phase A,

$$\left.\begin{matrix} 1 & 51 & 44 & 37 & 30 & 23 & 16 & 9 & 2 & 52 & 45 & 38 & 31 & 24 & 17 & 10 & 3 & 53 & 46 \\ 58 & 108 & 101 & 94 & 87 & 80 & 73 & 66 & 59 & 109 & 102 & 95 & 88 & 81 & 74 & 67 & 60 & 110 & 103 \\ 115 & 165 & 158 & 151 & 144 & 137 & 130 & 123 & 116 & 166 & 159 & 152 & 145 & 138 & 131 & 124 & 117 & 167 & 160 \end{matrix}\right\} \quad \text{D-series}$$

Applying rules (e) to (h) of Art. 7-10 with the changes indicated above, the 6 parts (waves) of both windings of phase A are:

1	158	144	130	116	102	88	74	60	46	= 1st part of 1st winding
51	37	23	9	166	152	138	124	110		= 1st part of 2nd winding
58	44	30	16	2	159	145	131	117	103	= 2nd part of 1st winding
108	94	80	66	52	38	24	10	167		= 2nd part of 2nd winding
115	101	87	73	59	45	31	17	3	160	= 3rd part of 1st winding
165	151	137	123	109	95	81	67	53		= 3rd part of 2nd winding

In order to lay out the winding, start with lower conductor 1 and connect it with the upper conductor 1 + 171 - 7 = 165, then connect this conductor with the second lower conductor of the first part of the first winding, 158, and so forth. The same is to be done with the other 5 parts, starting with slots 51, 58, 108, 115 and 165, respectively. The starts of both windings are:

$A1_1 = 1$ $\qquad$ $A2_1 = 51$

$A1_3 = 58$ $\qquad$ $A2_3 = 108$

$A1_5 = 115$ $\qquad$ $A2_5 = 165$

This can be obtained also from Eqs. 7-8 and 7-9. The ends of the 6 parts lie in the upper conductors (Eqs. 7-18 and 7-19):

$A1_2 = 1 + (S-\frac{19-1}{2} \times 14 - 7) = 1 + 38 = 39$ $\qquad$ $A2_2 = 51 + (S-\frac{19-3}{2} \times 14 - 7) = 51 + 52 = 103$

$A1_4 = 58 + 38 = 96$ $\qquad$ $A2_4 = 108 + 52 = 160$

$A1_6 = 115 + 38 = 153$ $\qquad$ $A2_6 = 165 + 52 - 171 = 46$

Since d is even, the starts of all parts of the first winding of the 2 interlaced windings have the same polarity and also the starts of all parts of the second winding have the same polarity. Further, the quantity P which determines the magnitude of D is odd, and this means that the polarities of the starts of the first parts of both windings are opposite. This yields Fig. 7-50 for the polarities of the starts and the ends of all phases.

As explained previously, the series connection can be accomplished in 3 different ways. The shortest connectors are obtained when $A1_2$ is connected with $A2_6$, $A1_4$ with $A2_2$, $A1_6$ with $A2_4$, $A1_3$ with $A2_3$, and $A1_5$ with $A2_5$. $A1_1$ and $A2_1$ are the leads. Only 3 parallel circuits are possible. For parallel connection, connect first $A1_2$ with $A2_6$, $A1_4$ with $A2_2$, and $A1_6$ with $A2_4$, and then connect $A1_1$, $A1_3$, $A1_5$ to one lead and $A2_1$, $A2_3$, $A2_5$ to the other lead.

↑ $A1_1$	$A1_2$ ↓	↑ $C1_1$	$C1_2$ ↓	↑ $B1_1$	$B1_2$ ↓
↑ $A1_3$	$A1_4$ ↓	↑ $C1_3$	$C1_4$ ↓	↑ $B1_3$	$B1_4$ ↓
↑ $A1_5$	$A1_6$ ↓	↑ $C1_5$	$C1_6$ ↓	↑ $B1_5$	$B1_6$ ↓
↓ $A2_1$	$A2_2$ ↑	↓ $C2_1$	$C2_2$ ↑	↓ $B2_1$	$B2_2$ ↑
↓ $A2_3$	$A2_4$ ↑	↓ $C2_3$	$C2_4$ ↑	↓ $B2_3$	$B2_4$ ↑
↓ $A2_5$	$A2_6$ ↑	↓ $C2_5$	$C2_6$ ↑	↓ $B2_5$	$B2_6$ ↑

$a = \pm 2$ d = even P = odd

(P = always odd for d = even)

Figure 1 following the letter designating a phase denotes the first of the interlaced windings.

Figure 2 following the letter designating a phase denotes the second of the interlaced windings.

Subscripts 1, 3, 5, etc., denote the beginnings of the parts of the interlaced windings.

Subscripts 2, 4, 6, etc., denote the ends of the parts of the interlaced windings.

Note that both windings cannot be connected in parallel; they must be connected in series.

Fig. 7-50. Polarities of the starts and ends of all 3 phases of a winding with $a = \pm 2$, d = even, and P = odd.

The starts and ends of phases C and B lie in slots (Eqs. 7-10 to 7-13 and Eqs. 7-18 and 7-19):

$$
\begin{aligned}
Cl_1 &= 1 + 19 \times 50 - 16 \times 57 = 39 \\
Cl_2 &= 39 + \left[S - \frac{19-1}{2} \times 14 - 7\right] = 39 + 38 = 77 \\
Cl_3 &= 39 + 57 = 96 \\
Cl_4 &= 96 + 38 = 134 \\
Cl_5 &= 39 + 2 \times 57 = 153 \\
Cl_6 &= 153 + 38 = 191 - 171 = 20
\end{aligned}
$$

$$
\begin{aligned}
C2_1 &= 39 + 50 - 57 = 32 \\
C2_2 &= 32 + \left[S - \frac{19-3}{2} \times 14 - 7\right] = 32 + 52 = 84 \\
C2_3 &= 32 + 57 = 89 \\
C2_4 &= 89 + 52 = 141 \\
C2_5 &= 32 + 2 \times 57 = 146 \\
C2_6 &= 146 + 52 - 171 = 27
\end{aligned}
$$

$$
\begin{aligned}
Bl_1 &= 1 + 2 \times 19 \times 50 - 33 \times 57 = 20 \\
Bl_2 &= 20 + 38 = 58 \\
Bl_3 &= 20 + 57 = 77 \\
Bl_4 &= 77 + 38 = 115 \\
Bl_5 &= 20 + 2 \times 57 = 134 \\
Bl_6 &= 134 + 38 = 172 - 171 = 1
\end{aligned}
$$

$$
\begin{aligned}
B2_1 &= 20 + 50 - 57 = 13 \\
B2_2 &= 13 + 52 = 65 \\
B2_3 &= 13 + 57 = 70 \\
B2_4 &= 70 + 52 = 122 \\
B2_5 &= 13 + 2 \times 57 = 127 \\
B2_6 &= 127 + 52 - 171 = 8
\end{aligned}
$$

For equal mechanical spacing of the beginnings of the phases, phase B should start in slot $1 + \frac{S}{3} = 58$, and phase C in slot $1 + 2 \times (\frac{S}{3}) = 115$ of vice versa. Bl_2 lies in 58, but no start or end of C lies in 115. In this case equal mechanical spacing is not possible because 24 (= No.of poles) is a multiple of 6 (see Art. 6-3). Checking shows that $Bl_3 = 77$ and $Cl_1 = 39$ can be used as phase beginnings. The angles are $(Bl_3 - 1) \times \frac{d}{N} \times 60 = 76 \times \frac{8}{19} \times 60 = 1920 - 5 \times 360 = 120^\circ$, and $(Cl_1 - 1) \times \frac{d}{N} \times 60 = 38 \times \frac{8}{19} \times 60 - 2 \times 360 = 240^\circ$.

For series or parallel connection of phases B and C, the same considerations apply as to phase A and the connections are to be made in such a manner that $A1_1$, $B1_3$ and $C1_1$ go either to the line or to the slip rings. Fig. 7-35 shows the Working Diagram, Fig. 7-35 a the fully developed Winding Diagram, and Table 7-35 the Connection Table for the example described above.

7-12. Layout of a Winding with a Larger than 2. As mentioned previously (see Art. 7-4), the windings with a larger than 1 can be considered as consisting of a interlaced windings. The number of parts per phase of these windings is $\left[a \times \frac{(\text{No. of poles})}{d}\right]$, each winding having $\frac{(\text{No. of poles})}{d}$ parts.

When $\frac{N}{a}$ is an integer, all windings have the same number of conductors (coils) per part; when $\frac{N}{a}$ is a fractional number, the windings have different numbers of conductors per part. In the first case, the layout of these windings is similar to that of the windings with $a = \pm 2$ and N = even; in the second case, the layout is similar to that of the windings with $a = \pm 2$ and N = odd. As before, the plus sign before a indicates that the winding progresses clockwise, the negative sign that it progresses counter-clockwise. The rules given in Arts. 7-10 and 7-11 apply here, but with some modifications.

Applying the rules (a) to (d) of Art. 7-10, the $(\frac{\text{No. of poles}}{d})$ D-series of phase A are determined. Then, starting with conductor 1, a certain number of conductors (N1) will be found which follow the winding-pitch series. Now starting with the conductors 1 + D, 1 + 2D, ... 1 + (a-1)D, determine again the numbers of conductors N2, N3 ... which follow the winding-pitch series. N1, N2, N3 ... are then the numbers of coils in the parts of the a interlaced windings. N1 + N2 + N3 + ... must be equal to N.

Thus for the first parts of phase A,

$$A1_1 = 1 \qquad A2_1 = 1 + D \qquad A3_1 = 1 + 2D \ldots \qquad (7\text{-}20)$$

Note that $A2_1$, $A3_1$ ... must be smaller than 3N, otherwise subtract 3N, 6N . . .

The starts of the second parts of the a interlaced windings of phase A are found by adding 3N to the starts of the first parts, and the starts of the third parts by adding 6N to the starts of the first parts. Thus:

$$A1_3 = 1 + 3N \quad A2_3 = A2_1 + 3N \quad A3_3 = A3_1 + 3N \ldots$$
$$A1_5 = 1 + 6N \quad A2_5 = A2_1 + 6N \quad A3_5 = A3_1 + 6N \ldots \qquad (7\text{-}21)$$

The ends of the first winding (A1) with N1 coils are:

Start + [(N1-1) x winding pitch + back pitch], when a is positive (7-22)

Start + [(S - (N1-1) x winding pitch - back pitch)], when a is negative (7-23)

The ends of the second winding (A2) with N2 coils are:

Start + [(N2-1) x winding pitch + back pitch], when a is positive (7-24)

Start + [S-(N2-1) x winding pitch - back pitch], when a is negative (7-25)

The ends of the third winding (A3) with N3 coils are:

Start + [(N3-1) x winding pitch + back pitch], when a is positive (7-26)

Start + [S-(N3-1) x winding pitch - back pitch], when a is negative (7-27)

and so forth.

The start of the first part of the first winding of phase C is

$$C1_1 = 1 + ND \qquad (7\text{-}28)$$

and the start of the first part of the first winding of phase B is

$$B1_1 = 1 + 2ND \qquad (7\text{-}29)$$

Applying Eq. 7-20,

$$C2_1 = C1_1 + D \qquad C3_1 = C1_1 + 2D \qquad (7\text{-}30)$$
$$B2_1 = B1_1 + D \qquad B3_1 = B1_1 + 2D \qquad (7\text{-}31)$$

Note that the starts of the first parts of all windings, $C1_1$, $C2_1$, $C3_1$ ... $B1_1$, $B2_1$, $B3_1$ ... must be smaller than 3N, otherwise subtract 3N, 6N ...

Applying Eq. 7-21,

$$\begin{matrix} B1_3 = B1_1 + 3N & B2_3 = B2_1 + 3N & B3_3 = B3_1 + 3N \\ B1_5 = B1_1 + 6N & B2_5 = B2_1 + 6N & B3_5 = B3_1 + 6N \end{matrix} \qquad (7\text{-}32)$$

and

$$\begin{matrix} C1_3 = C1_1 + 3N & C2_3 = C2_1 + 3N & C3_3 = C1_1 + 3N \\ C1_5 = C1_1 + 6N & C2_5 = C2_1 + 6N & C3_5 = C1_1 + 6N \end{matrix} \qquad (7\text{-}33)$$

The ends of the first winding of phases C and B (C1 and B1) with N1 conductors per part are given by Eqs. 7-22 and 7-23; the ends of the second winding of phases C and B (C2 and B2) with N2 conductors per part are given by Eqs. 7-24 and 7-25; the ends of the third winding of phases C and B (C3 and B3) with N3 conductors per part are given by Eqs. 7-26 and 7-27, and so forth.

In this way, the starts and ends of all parts are determined. If the polarities of all parts are known, the connections for series and parallel connection can be determined. The polarities of the starts of the parts of one and the same winding ($A1_1$, $A1_3$, $A1_5$, or $A2_1$, $A2_3$, $A2_5$ ...) are determined by d; they alternate when d is odd; they are all the same, when d is even. The polarities of the starts of the first parts of different windings ($A1_1$, $A2_1$, $A3_1$ ... or $B1_1$, $B2_1$, $B3_1$ ...) are best determined by the general rule given in Art. 7-6.

$\uparrow A1_1 \ \downarrow A1_3 \ \uparrow A1_5$	$\uparrow A1_1 \ \downarrow A1_3 \ \uparrow A1_5$
$\downarrow A2_1 \ \uparrow A2_3 \ \downarrow A2_5$	$\uparrow A2_1 \ \downarrow A2_3 \ \uparrow A2_5$
$\uparrow A3_1 \ \downarrow A3_3 \ \uparrow A3_5$	$\downarrow A3_1 \ \uparrow A3_3 \ \downarrow A3_5$
$\uparrow C1_1 \ \downarrow C1_3 \ \uparrow C1_5$	$\uparrow C1_1 \ \downarrow C1_3 \ \uparrow C1_5$
$\downarrow C2_1 \ \uparrow C2_3 \ \downarrow C2_5$	$\uparrow C2_1 \ \downarrow C2_3 \ \uparrow C2_5$
$\downarrow C3_1 \ \uparrow C3_3 \ \downarrow C3_5$	$\downarrow C3_1 \ \uparrow C3_3 \ \downarrow C3_5$
$\uparrow B1_1 \ \downarrow B1_3 \ \uparrow B1_5$	$\uparrow B1_1 \ \downarrow B1_3 \ \uparrow B1_5$
$\uparrow B2_1 \ \downarrow B2_3 \ \uparrow B2_5$	$\downarrow B2_1 \ \uparrow B2_3 \ \downarrow B2_5$
$\downarrow B3_1 \ \uparrow B3_3 \ \downarrow B3_5$	$\downarrow B3_1 \ \uparrow B3_3 \ \downarrow B3_5$
a = ± 3 d = odd P = odd	a = ± 3 d = odd P = even

(a = ± 3 does not occur when d = even number)

This figure shows only the polarities of the beginnings of the 3 interlaced windings. The polarities of the ends are opposite to those of the beginnings.

Figure 1 following the letter designating a phase denotes the first of the interlaced windings.

Figure 2 following the letter designating a phase denotes the second of the interlaced windings.

Figure 3 following the letter designating a phase denotes the third of the interlaced windings.

Subscripts 1, 3, 5, etc. denote the beginnings of the parts of the interlaced windings.

Note that both windings cannot be connected in parallel; they must be connected in series.

Fig. 7-51. Polarities of the starts and ends of all 3 phases of a winding with a = ± 3, d = odd, P = odd, and a = ± 3, d = odd, P = even.

The polarities of the first parts of the first winding ($A1_1$, $B1_1$, $C1_1$) can be assumed arbitrarily. The polarity rules fix then the polarities of all other parts. For example, for a = ± 3, d = odd, and P = odd or even, the polarities are such as shown on Fig. 7-51. Fig. 7-43 shows a fully developed diagram with a = + 3, d = odd, and P = odd. For the connections of the parts, use Fig. 7-51.

7-13. Layout for 2 or More Parallel Paths. Contrary to the integral slot and (integral + 1/2) - slot wave windings in which each phase consists of 2 parts, the windings treated in this chapter have $\left[\frac{\text{No. of poles}}{d} \times a\right]$ parts per phase. In the integral-slot and (integral + 1/2) - slot windings, special methods discussed in Arts. 6-9 and 6-10 were developed to lay out the windings for 2 or more parallel paths. For the windings treated in this chapter, the procedure of laying out the winding for 2 or more parallel paths is exactly the same as for series connection. The number of parallel paths is limited by the requirements outlined in Arts. 7-5. The proper connection of tthe parts into parallel paths is based upon the polarities of their starts and ends which are regulated by the values of d and P as outlined in Art. 7-6.

TABLE 7-1

Connection Table for 84 Slots, 10 Poles, spp=2 4/5; (y=17; y_b=8; y_f=9; a=+1; d=odd)

REFERENCE WORKING DIAGRAM Fig. 7-1

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	14	↑	A_1 = 1	A_2 = 62	↓	↑	B_1 = 15	B_2 = 76	↓	↑	C_1 = 29	C_2 = 6	↓
	14	↓	A_3 = 43	A_4 = 20	↑	↓	B_3 = 57	B_4 = 34	↑	↓	C_3 = 71	C_4 = 48	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_3$
	B_3	$B_2 \rightarrow B_4$	B_1	$B_1 \rightarrow C_1$
	C_1	$C_2 \rightarrow C_4$	C_3	$C_3 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_2 \rightarrow B_3$
	$B_2 \rightarrow B_3$	-	$B_1 \rightarrow B_4$	$B_1 \rightarrow B_4 \rightarrow C_1 \rightarrow C_4$
	$C_1 \rightarrow C_4$	-	$C_2 \rightarrow C_3$	$C_2 \rightarrow C_3 \rightarrow A_1 \rightarrow A_4$

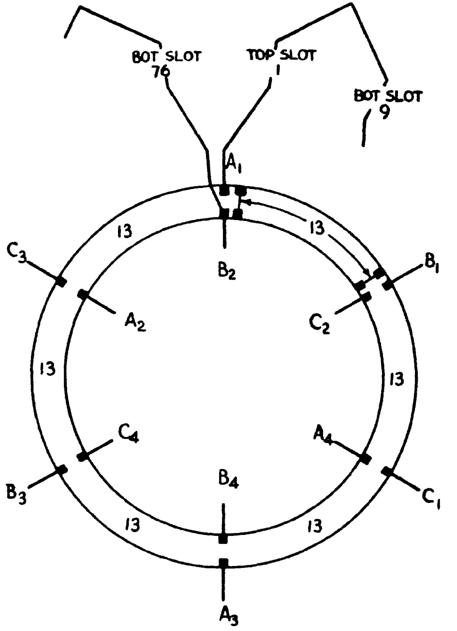


Fig. 7-1. Working Diagram for 84 slots, 10 poles, spp = 2 4/5

TABLE 7-2

Connection Table for 168 Slots, 20 Poles, spp=2 4/5; $(y=17;\ y_b=8;\ y_f=9;\ a=+1;\ d=\text{odd})$

REFERENCE WORKING DIAGRAM Fig. 7-2

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	14	↑	$A_1 = 1$	$A_2 = 62$	↓	↑	$B_1 = 15$	$B_2 = 76$	↓	↑	$C_1 = 29$	$C_2 = 90$	↓
	14	↓	$A_3 = 43$	$A_4 = 104$	↑	↓	$B_3 = 57$	$B_4 = 118$	↑	↓	$C_3 = 71$	$C_4 = 132$	↑
	14	↑	$A_5 = 85$	$A_6 = 146$	↓	↑	$B_5 = 99$	$B_6 = 160$	↓	↑	$C_5 = 113$	$C_6 = 6$	↓
	14	↓	$A_7 = 127$	$A_8 = 20$	↑	↓	$B_7 = 141$	$B_8 = 34$	↑	↓	$C_7 = 155$	$C_8 = 48$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \to A_4$ $A_3 \to A_5$ $A_6 \to A_8$	A_7	$A_7 \to C_5$
	B_3	$B_4 \to B_6$ $B_5 \to B_7$ $B_2 \to B_8$	B_1	$B_1 \to A_1$
	C_5	$C_2 \to C_4$ $C_1 \to C_7$ $C_6 \to C_8$	C_3	$C_3 \to B_3$
2	$A_1 \to A_8$	$A_2 \to A_4$ $A_5 \to A_7$	$A_3 \to A_6$	$A_3 \to A_6 \to B_2 \to B_3$
	$B_2 \to B_3$	$B_4 \to B_6$ $B_1 \to B_7$	$B_5 \to B_8$	$B_5 \to B_8 \to C_4 \to C_5$
	$C_4 \to C_5$	$C_1 \to C_3$ $C_6 \to C_8$	$C_2 \to C_7$	$C_2 \to C_7 \to A_1 \to A_8$
4	$A_1 \to A_4 \to A_5 \to A_8$	-	$A_2 \to A_3 \to A_6 \to A_7$	$A_2 \to A_3 \to A_6 \to A_7 \to B_2 \to B_3 \to B_6 \to B_7$
	$B_2 \to B_3 \to B_6 \to B_7$	-	$B_1 \to B_4 \to B_5 \to B_8$	$B_1 \to B_4 \to B_5 \to B_8 \to C_1 \to C_4 \to C_5 \to C_8$
	$C_1 \to C_4 \to C_5 \to C_8$	-	$C_2 \to C_3 \to C_6 \to C_7$	$C_2 \to C_3 \to C_6 \to C_7 \to A_1 \to A_4 \to A_5 \to A_8$

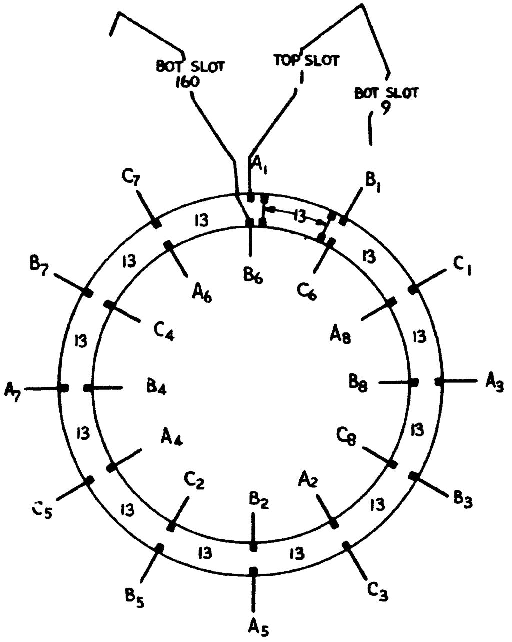


Fig. 7-2. Working Diagram for 168 slots, 20 poles, spp = 2 4/5

TABLE 7-3

Connection Table for 144 Slots, 10 Poles, spp=4 4/5; $(y=29;\ y_b=14;\ y_f=15;\ a=+1;\ d=\text{odd})$

REFERENCE WORKING DIAGRAM Fig. 7-3

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	24	↑	$A_1 = 1$	$A_2 = 106$	↓	↑	$B_1 = 25$	$B_2 = 130$	↓	↑	$C_1 = 49$	$C_2 = 10$	↓
	24	↓	$A_3 = 73$	$A_4 = 34$	↑	↓	$B_3 = 97$	$B_4 = 58$	↑	↓	$C_3 = 121$	$C_4 = 82$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_3$
	B_3	$B_2 \rightarrow B_4$	B_1	$B_1 \rightarrow C_1$
	C_1	$C_2 \rightarrow C_4$	C_3	$C_3 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_2 \rightarrow B_3$
	$B_2 \rightarrow B_3$	-	$B_1 \rightarrow B_4$	$B_1 \rightarrow B_4 \rightarrow C_1 \rightarrow C_4$
	$C_1 \rightarrow C_4$	-	$C_2 \rightarrow C_3$	$C_2 \rightarrow C_3 \rightarrow A_1 \rightarrow A_4$

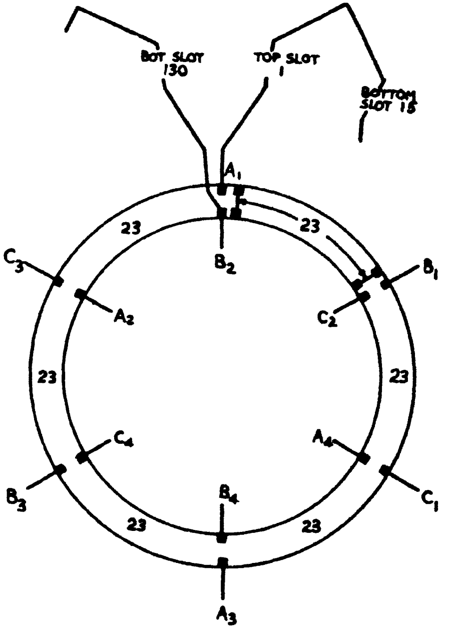


Fig. 7-3. Working Diagram for 144 slots, 10 poles, spp = 4 4/5

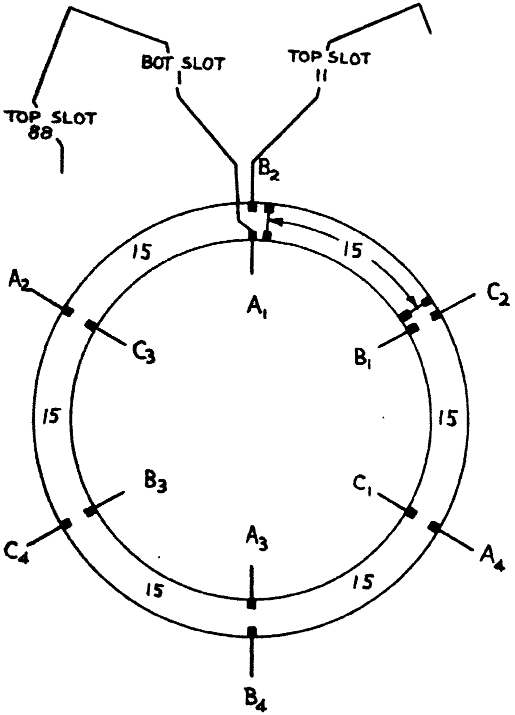


Fig. 7-4. Working Diagram for 96 slots, 10 poles, spp = 3 1/5

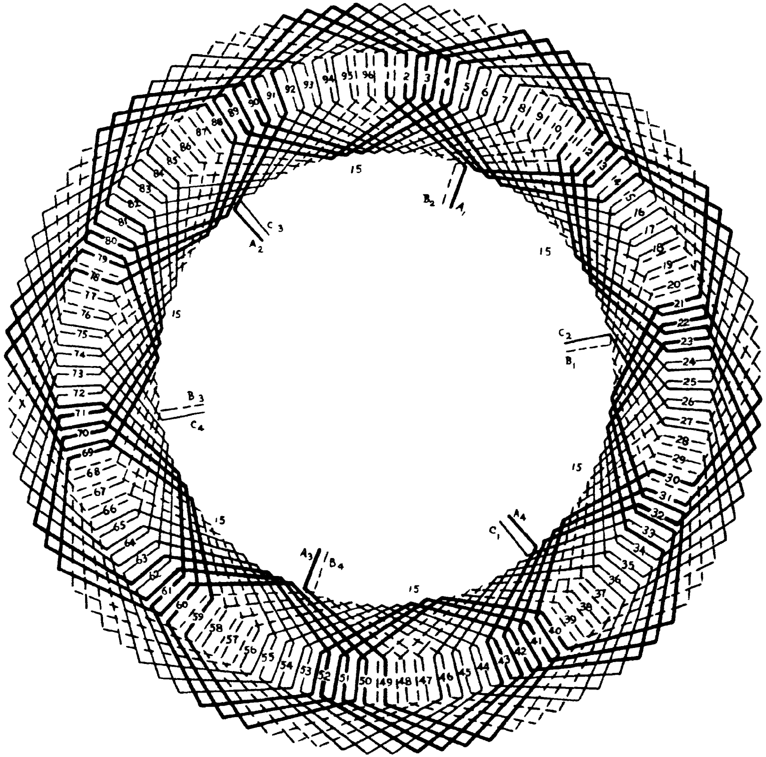


Fig. 7-4a. Fully developed diagram for 96 slots, 10 poles, spp = 3 1/5

TABLE 7-4

Connection Table for 96 Slots, 10 Poles, spp=3 1/5; $(y=19;\ y_b=9;\ y_f=10;\ a=-1;\ d=\text{odd})$

REFERENCE WORKING DIAGRAM Fig. 7-4

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	16	↑	$A_1 = 1$	$A_2 = 91$	↓	↑	$B_1 = 17$	$B_2 = 11$	↓	↑	$C_1 = 33$	$C_2 = 27$	↓
	16	↓	$A_3 = 49$	$A_4 = 43$	↑	↓	$B_3 = 65$	$B_4 = 59$	↑	↓	$C_3 = 81$	$C_4 = 75$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_3$
	B_3	$B_2 \rightarrow B_4$	B_1	$B_1 \rightarrow C_1$
	C_1	$C_2 \rightarrow C_4$	C_3	$C_3 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_2 \rightarrow B_3$
	$B_2 \rightarrow B_3$	-	$B_1 \rightarrow B_4$	$B_1 \rightarrow B_4 \rightarrow C_1 \rightarrow C_4$
	$C_1 \rightarrow C_4$	-	$C_2 \rightarrow C_3$	$C_2 \rightarrow C_3 \rightarrow A_1 \rightarrow A_4$

TABLE 7-5

Connection Table for 192 Slots, 20 Poles, spp=3 1/5; (y=19; y_b=9; y_f=10; a=-1; d=odd)

REFERENCE WORKING DIAGRAM Fig. 7-5

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	16	↑	A_1 = 1	A_2 = 91	↓	↑	B_1 = 17	B_2 = 107	↓	↑	C_1 = 33	C_2 = 123	↓
	16	↓	A_3 = 49	A_4 = 139	↑	↓	B_3 = 65	B_4 = 155	↑	↓	C_3 = 81	C_4 = 171	↑
	16	↑	A_5 = 97	A_6 = 187	↓	↑	B_5 = 113	B_6 = 11	↓	↑	C_5 = 129	C_6 = 27	↓
	16	↓	A_7 = 145	A_8 = 43	↑	↓	B_7 = 161	B_8 = 59	↑	↓	C_7 = 177	C_8 = 75	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \to A_4$ $A_3 \to A_5$ $A_6 \to A_8$	A_7	$A_7 \to C_5$
	B_3	$B_4 \to B_6$ $B_5 \to B_7$ $B_2 \to B_8$	B_1	$B_1 \to A_1$
	C_5	$C_2 \to C_4$ $C_1 \to C_7$ $C_6 \to C_8$	C_3	$C_3 \to B_3$
2	$A_1 \to A_8$	$A_2 \to A_4$ $A_5 \to A_7$	$A_3 \to A_6$	$A_3 \to A_6 \to B_2 \to B_3$
	$B_2 \to B_3$	$B_4 \to B_8$ $B_1 \to B_7$	$B_5 \to B_8$	$B_5 \to B_8 \to C_4 \to C_5$
	$C_4 \to C_5$	$C_1 \to C_3$ $C_6 \to C_8$	$C_2 \to C_7$	$C_2 \to C_7 \to A_1 \to A_8$
	$A_1 \to A_4 \to A_5 \to A_8$	-	$A_2 \to A_3 \to A_6 \to A_7$	$A_2 \to A_3 \to A_6 \to A_7 \to B_2 \to$ $B_3 \to B_6 \to B_7$
4	$B_2 \to B_3 \to B_6 \to B_7$	-	$B_1 \to B_4 \to B_5 \to B_8$	$B_1 \to B_4 \to B_5 \to B_8 \to C_1 \to$ $C_4 \to C_5 \to C_8$
	$C_1 \to C_4 \to C_5 \to C_8$	-	$C_2 \to C_3 \to C_6 \to C_7$	$C_2 \to C_3 \to C_6 \to C_7 \to A_1 \to$ $A_4 \to A_5 \to A_8$

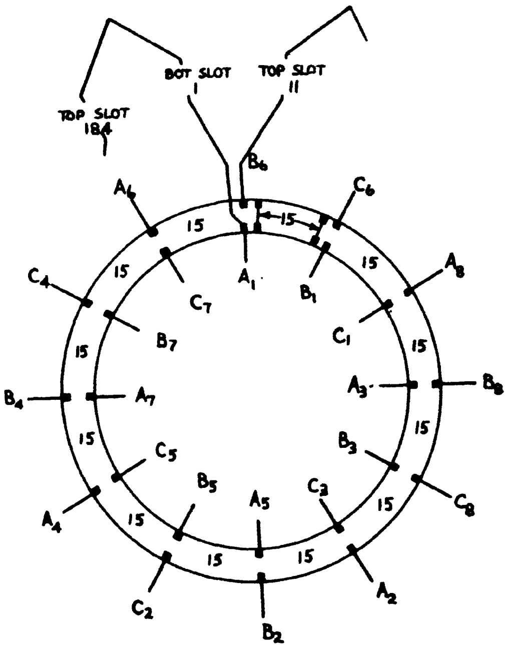


Fig. 7-5. Working Diagram for 192 slots, 20 poles.
spp = 3 1/5

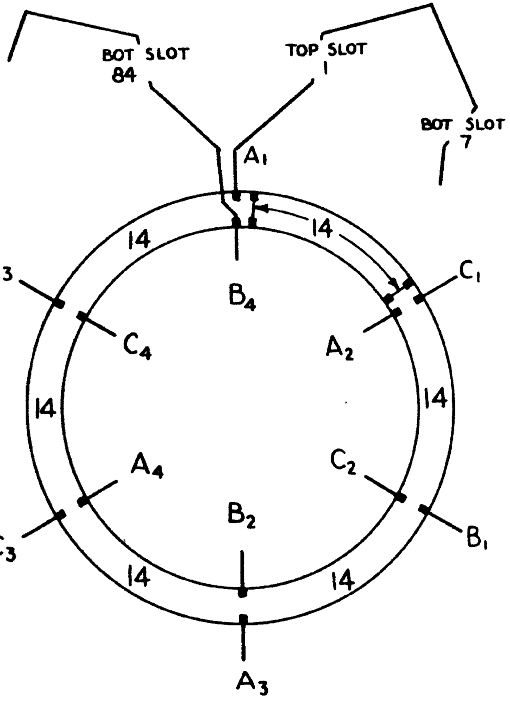


Fig. 7-6. Working Diagram for 90 slots, 14 poles, spp = 2 1/7

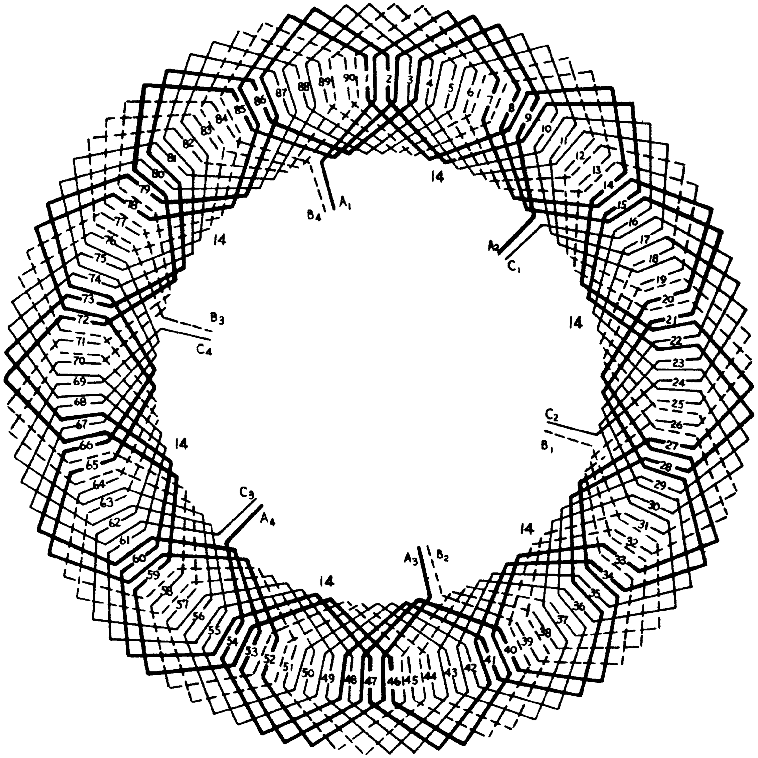


Fig. 7-6a. Fully developed diagram for 90 slots, 14 poles, spp = 2 1/7

TABLE 7-6

Connection Table for 90 Slots, 14 Poles, spp=2 1/7; ($y=13$; $y_b=6$; $y_f=7$; $a=+1$; $d=odd$)

REFERENCE WORKING DIAGRAM Fig. 7-6

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	15	↑	$A_1 = 1$	$A_2 = 9$	↓	↑	$B_1 = 31$	$B_2 = 39$	↓	↑	$C_1 = 16$	$C_2 = 24$	↓
	15	↓	$A_3 = 46$	$A_4 = 54$	↑	↓	$B_3 = 76$	$B_4 = 84$	↑	↓	$C_3 = 61$	$C_4 = 69$	↑

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

TABLE 7-7

Connection Table for 180 Slots, 28 Poles, spp=2 1/7; ($y=13$; $y_b=6$; $y_f=7$; $a=+1$; d=odd)

REFERENCE WORKING DIAGRAM Fig. 7-7

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	15	↑	A_1 = 1	A_2 = 9	↓	↑	B_1 = 31	B_2 = 39	↓	↑	C_1 = 16	C_2 = 24	↓
	15	↓	A_3 = 46	A_4 = 54	↑	↓	B_3 = 76	B_4 = 84	↑	↓	C_3 = 61	C_4 = 69	↑
	15	↑	A_5 = 91	A_6 = 99	↓	↑	B_5 = 121	B_6 = 129	↓	↑	C_5 = 106	C_6 = 114	↓
	15	↓	A_7 = 136	A_8 = 144	↑	↓	B_7 = 166	B_8 = 174	↑	↓	C_7 = 151	C_8 = 159	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \to A_4$ $A_3 \to A_5$ $A_6 \to A_8$	A_7	$A_7 \to B_5$
	B_5	$B_2 \to B_4$ $B_1 \to B_7$ $B_6 \to B_8$	B_3	$B_3 \to C_3$
	C_3	$C_4 \to C_6$ $C_5 \to C_7$ $C_2 \to C_8$	C_1	$C_1 \to A_1$
2	$A_1 \to A_8$	$A_2 \to A_4$ $A_5 \to A_7$	$A_3 \to A_6$	$A_3 \to A_6 \to B_4 \to B_5$
	$B_4 \to B_5$	$B_6 \to B_8$ $B_1 \to B_3$	$B_7 \to B_2$	$B_7 \to B_2 \to C_2 \to C_3$
	$C_2 \to C_3$	$C_1 \to C_7$ $C_4 \to C_6$	$C_8 \to C_5$	$C_8 \to C_5 \to A_1 \to A_8$
4	$A_1 \to A_4 \to A_5 \to A_8$	-	$A_2 \to A_3 \to A_6 \to A_7$	$A_2 \to A_3 \to A_6 \to A_7 \to B_1 \to B_4 \to B_5 \to B_8$
	$B_1 \to B_4 \to B_5 \to B_8$	-	$B_2 \to B_3 \to B_6 \to B_7$	$B_2 \to B_3 \to B_6 \to B_7 \to C_2 \to C_3 \to C_6 \to C_7$
	$C_2 \to C_3 \to C_6 \to C_7$	-	$C_1 \to C_4 \to C_5 \to C_8$	$C_1 \to C_4 \to C_5 \to C_8 \to A_1 \to A_4 \to A_5 \to A_8$

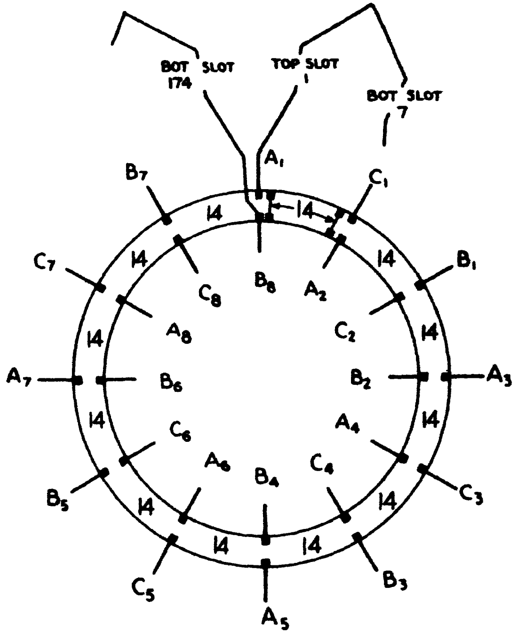


Fig. 7-7. Working Diagram for 180 slots, 28 poles, spp = 2 1/7

TABLE 7-8

Connection Table for 240 Slots, 14 Poles, spp=5 5/7; (y=34; y_b=17; y_f=17; a=-2; d-odd; p-even)

REFERENCE WORKING DIAGRAM Fig. 7-8

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	20	↑	$A1_1$ = 1	$A1_2$ = 58	↓	↑	$B1_1$ = 81	$B1_2$ = 138	↓	↑	$C1_1$ = 41	$C1_2$ = 98	↓
	20	↑	$A2_1$ = 104	$A2_2$ = 161	↓	↓	$B2_1$ = 64	$B2_2$ = 121	↑	↓	$C2_1$ = 24	$C2_2$ = 81	↑
	20	↓	$A1_3$ = 121	$A1_4$ = 178	↑	↓	$B1_3$ = 201	$B1_4$ = 18	↑	↓	$C1_3$ = 161	$C1_4$ = 218	↑
	20	↓	$A2_3$ = 224	$A2_4$ = 41	↑	↑	$B2_3$ = 184	$B2_4$ = 1	↓	↑	$C2_3$ = 144	$C2_4$ = 201	↓

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_4$ $A2_1 \rightarrow A2_3$ $A1_4 \rightarrow A2_2$	$A1_3$	$A1_3 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B2_3$ $B1_4 \rightarrow B2_4$	$B1_3$	$B1_3 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C2_3$ $C1_4 \rightarrow C2_4$	$C1_1$	$C1_1 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_4$	$A1_2 \rightarrow A2_4$ $A1_3 \rightarrow A2_1$	$A2_2 \rightarrow A2_3$	$A2_2 \rightarrow A2_3 \rightarrow B1_1 \rightarrow B1_4$
	$B1_1 \rightarrow B1_4$	$B1_2 \rightarrow B2_2$ $B1_3 \rightarrow B2_3$	$B2_1 \rightarrow B2_4$	$B2_1 \rightarrow B2_4 \rightarrow C1_2 \rightarrow C1_3$
	$C1_2 \rightarrow C1_3$	$C1_4 \rightarrow C2_4$ $C1_1 \rightarrow C2_1$	$C2_2 \rightarrow C2_3$	$C2_2 \rightarrow C2_3 \rightarrow A1_1 \rightarrow A1_4$

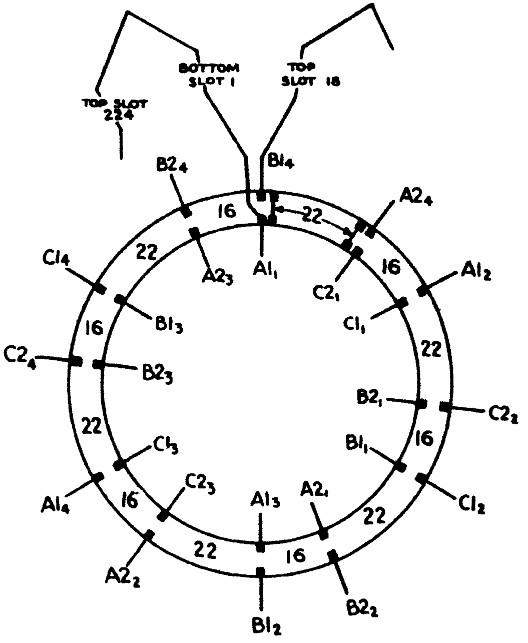


Fig. 7-8. Working Diagram for 240 slots, 14 poles, spp = 5 5/7

TABLE 7-9

Connection Table for 120 Slots, 14 Poles, spp=2 6/7; (y=17; y_b=8; y_f=9; a=-1; d=odd)

REFERENCE WORKING DIAGRAM Fig. 7-9

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	20	↑	A_1 = 1	A_2 = 30	↓	↑	B_1 = 41	B_2 = 70	↓	↑	C_1 = 21	C_2 = 50	↓
	20	↓	A_3 = 61	A_4 = 90	↑	↓	B_3 = 101	B_4 = 10	↑	↓	C_3 = 81	C_4 = 110	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

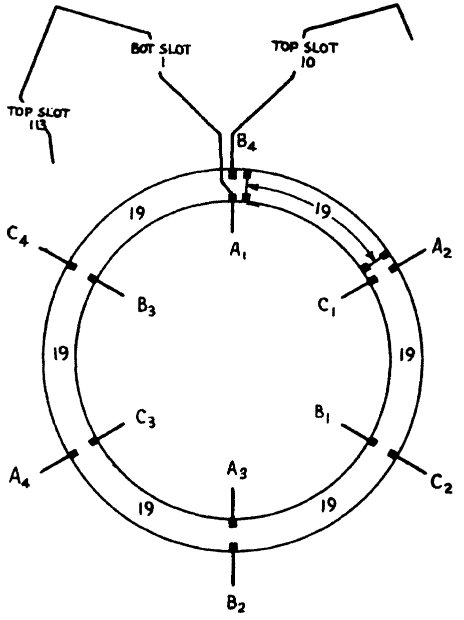


Fig. 7-9. Working Diagram for 120 slots, 14 poles, spp = 2 6/7

TABLE 7-10

Connection Table for 240 Slots, 28 Poles, spp=2 6/7; (y=17; y_b=8; y_f=9; a=-1; d=odd)

REFERENCE WORKING DIAGRAM Fig. 7-10

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	20	↑	A_1 = 1	A_2 = 150	↓	↑	B_1 = 41	B_2 = 190	↓	↑	C_1 = 21	C_2 = 170	↓
	20	↓	A_3 = 61	A_4 = 210	↑	↓	B_3 = 101	B_4 = 10	↑	↓	C_3 = 81	C_4 = 230	↑
	20	↑	A_5 = 121	A_6 = 30	↓	↑	B_5 = 161	B_6 = 70	↓	↑	C_5 = 141	C_6 = 50	↓
	20	↓	A_7 = 181	A_8 = 90	↑	↓	B_7 = 221	B_8 = 130	↑	↓	C_7 = 201	C_8 = 110	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$ $A_3 \rightarrow A_5$ $A_6 \rightarrow A_8$	A_7	$A_7 \rightarrow B_5$
	B_5	$B_2 \rightarrow B_4$ $B_1 \rightarrow B_7$ $B_6 \rightarrow B_8$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_4 \rightarrow C_6$ $C_5 \rightarrow C_7$ $C_2 \rightarrow C_8$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	$A_3 \rightarrow A_5$ $A_2 \rightarrow A_8$	$A_6 \rightarrow A_7$	$A_6 \rightarrow A_7 \rightarrow B_5 \rightarrow B_8$
	$B_5 \rightarrow B_8$	$B_4 \rightarrow B_6$ $B_1 \rightarrow B_7$	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_3 \rightarrow C_6$
	$C_3 \rightarrow C_6$	$C_2 \rightarrow C_4$ $C_5 \rightarrow C_7$	$C_1 \rightarrow C_8$	$C_1 \rightarrow C_8 \rightarrow A_1 \rightarrow A_4$
4	$A_1 \rightarrow A_4 \rightarrow A_5 \rightarrow A_8$	-	$A_2 \rightarrow A_3 \rightarrow A_6 \rightarrow A_7$	$A_2 \rightarrow A_3 \rightarrow A_6 \rightarrow A_7 \rightarrow B_1 \rightarrow B_4 \rightarrow B_5 \rightarrow B_8$
	$B_1 \rightarrow B_4 \rightarrow B_5 \rightarrow B_8$	-	$B_2 \rightarrow B_3 \rightarrow B_6 \rightarrow B_7$	$B_2 \rightarrow B_3 \rightarrow B_6 \rightarrow B_7 \rightarrow C_2 \rightarrow C_3 \rightarrow C_6 \rightarrow C_7$
	$C_2 \rightarrow C_3 \rightarrow C_6 \rightarrow C_7$	-	$C_1 \rightarrow C_4 \rightarrow C_5 \rightarrow C_8$	$C_1 \rightarrow C_4 \rightarrow C_5 \rightarrow C_8 \rightarrow A_1 \rightarrow A_4 \rightarrow A_5 \rightarrow A_8$

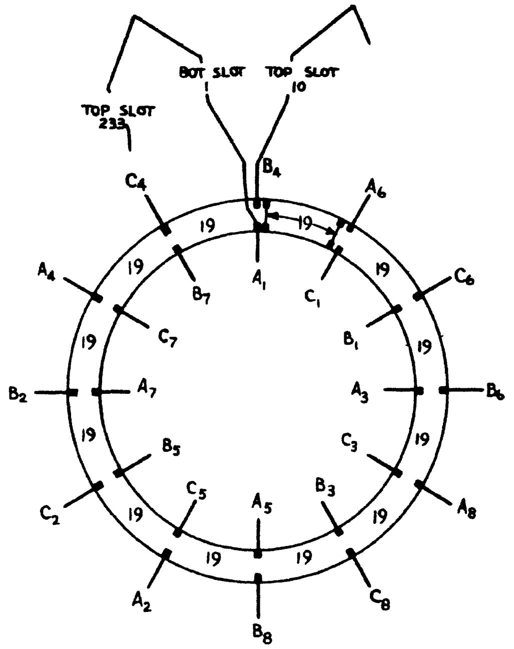


Fig. 7-10. Working Diagram for 240 slots, 28 poles, spp = 2 6/7

TABLE 7-11

Connection Table for 120 Slots, 22 Poles, spp=1 9/11; ($y=11$; $y_b=5$; $y_f=6$; $a=+1$; d=odd)

REFERENCE WORKING DIAGRAM Fig. 7-11

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	20	↑	A_1 = 1	A_2 = 95	↓	↑	B_1 = 21	B_2 = 115	↓	↑	C_1 = 41	C_2 = 15	↓
	20	↓	A_3 = 61	A_4 = 35	↑	↓	B_3 = 81	B_4 = 55	↑	↓	C_3 = 101	C_4 = 75	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_3$
	B_3	$B_2 \rightarrow B_4$	B_1	$B_1 \rightarrow C_1$
	C_1	$C_2 \rightarrow C_4$	C_3	$C_3 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_2 \rightarrow B_3$
	$B_2 \rightarrow B_3$	-	$B_1 \rightarrow B_4$	$B_1 \rightarrow B_4 \rightarrow C_1 \rightarrow C_4$
	$C_1 \rightarrow C_4$	-	$C_2 \rightarrow C_3$	$C_2 \rightarrow C_3 \rightarrow A_1 \rightarrow A_4$

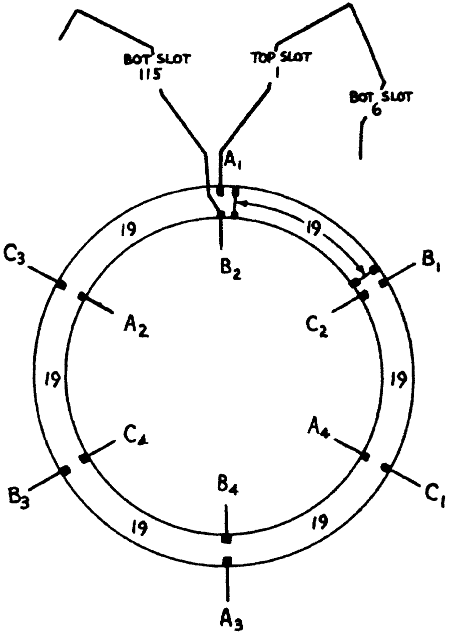


Fig. 7-11. Working Diagram for 120 slots, 22 poles, spp = 1 9/11

TABLE 7-12

Connection Table for 144 Slots, 22 Poles, spp=2 2/11; ($y=13$; $y_b=6$; $y_f=7$; $a=-1$; d=odd)

REFERENCE WORKING DIAGRAM Fig. 7-12

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	24	↑	A_1 = 1	A_2 = 128	↓	↑	B_1 = 25	B_2 = 8	↓	↑	C_1 = 49	C_2 = 32	↓
	24	↓	A_3 = 73	A_4 = 56	↑	↓	B_3 = 97	B_4 = 80	↑	↓	C_3 = 121	C_4 = 104	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_3$
	B_3	$B_2 \rightarrow B_4$	B_1	$B_1 \rightarrow C_1$
	C_1	$C_2 \rightarrow C_4$	C_3	$C_3 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_2 \rightarrow B_3$
	$B_2 \rightarrow B_3$	-	$B_1 \rightarrow B_4$	$B_1 \rightarrow B_4 \rightarrow C_1 \rightarrow C_4$
	$C_1 \rightarrow C_4$	-	$C_2 \rightarrow C_3$	$C_2 \rightarrow C_3 \rightarrow A_1 \rightarrow A_4$

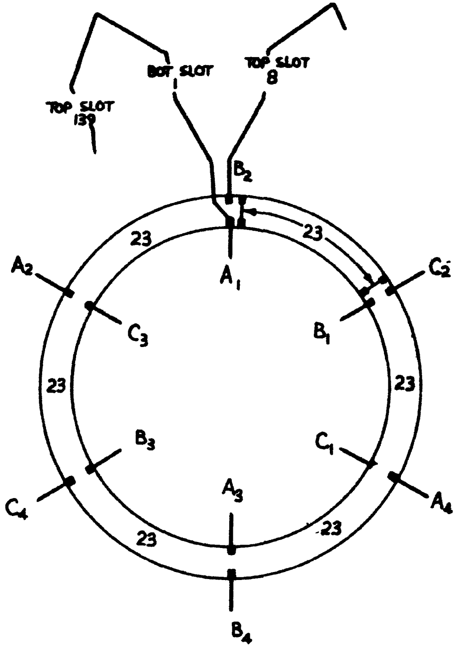


Fig. 7-12.. Working Diagram ror 144 slots, 22 poles, spp = 2 2/11

TABLE 7-13

Connection Table for 240 Slots, 22 Poles, spp=3 7/11; (y=22; y_b=11; y_f=11; a=+2; d=odd, P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-13

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	20	↑	$A1_1$ = 1	$A1_2$ = 190	↓	↑	$B1_1$ = 41	$B1_2$ = 230	↓	↑	$C1_1$ = 81	$C1_2$ = 30	↓
	20	↓	$A2_1$ = 12	$A2_2$ = 201	↑	↓	$B2_1$ = 52	$B2_2$ = 1	↑	↓	$C2_1$ = 92	$C2_2$ = 41	↑
	20	↓	$A1_3$ = 121	$A1_4$ = 70	↑	↓	$B1_3$ = 161	$B1_4$ = 110	↑	↓	$C1_3$ = 201	$C1_4$ = 150	↑
	20	↑	$A2_3$ = 132	$A2_4$ = 81	↓	↑	$B2_3$ = 172	$B2_4$ = 121	↓	↑	$C2_3$ = 212	$C2_4$ = 161	↓

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A2_3$ $A1_4 \rightarrow A2_4$	$A1_3$	$A1_3 \rightarrow B1_3$
	$B1_3$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B2_3$ $B1_4 \rightarrow B2_4$	$B1_1$	$B1_1 \rightarrow C1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C2_3$ $C1_4 \rightarrow C2_4$	$C1_3$	$C1_3 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_4$	$A1_2 \rightarrow A2_2$ $A1_3 \rightarrow A2_3$	$A2_1 \rightarrow A2_4$	$A2_1 \rightarrow A2_4 \rightarrow B1_2 \rightarrow B1_3$
	$B1_2 \rightarrow B1_3$	$B1_1 \rightarrow B2_1$ $B1_4 \rightarrow B2_4$	$B2_2 \rightarrow B2_3$	$B2_2 \rightarrow B2_3 \rightarrow C1_1 \rightarrow C1_4$
	$C1_1 \rightarrow C1_4$	$C1_2 \rightarrow C2_2$ $C1_3 \rightarrow C2_3$	$C2_1 \rightarrow C2_4$	$C2_1 \rightarrow C2_4 \rightarrow A1_1 \rightarrow A1_4$

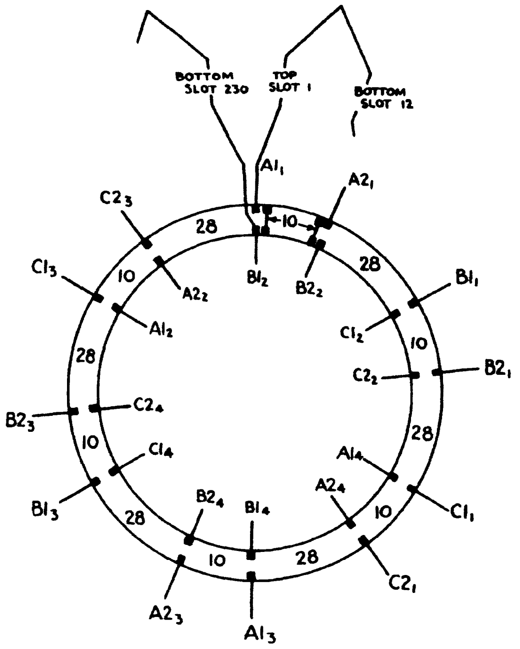


Fig.7-13. Working Diagram for 240 slots, 22 poles, spp = 3 7/11

TABLE 7-14

Connection Table for 144 Slots, 26 Poles, spp=1 11/13; $(y=11;\ y_b=5;\ y_f=6;\ a=-1;\ d=\text{odd})$

REFERENCE WORKING DIAGRAM Fig. 7-14

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	24	↑	A_1 = 1	A_2 = 31	↓	↑	B_1 = 49	B_2 = 79	↓	↑	C_1 = 25	C_2 = 55	↓
	24	↓	A_3 = 73	A_4 = 103	↑	↓	B_3 = 121	B_4 = 7	↑	↓	C_3 = 97	C_4 = 127	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

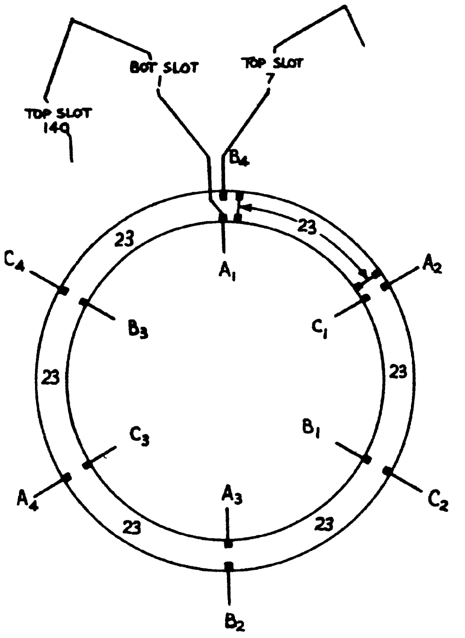


Fig. 7-14. Working Diagram for 144 slots, 26 poles, spp=1 11/13

TABLE 7-15

Connection Table for 168 Slots, 26 Poles, spp=2 2/13; $\left(y=13;\ y_b=6;\ y_f=7;\ a=+1;\ d=\text{odd}\right)$

REFERENCE WORKING DIAGRAM Fig. 7-15

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	28	↑	$A_1 = 1$	$A_2 = 22$	↓	↑	$B_1 = 57$	$B_2 = 78$	↓	↑	$C_1 = 29$	$C_2 = 50$	↓
	28	↓	$A_3 = 85$	$A_4 = 106$	↑	↓	$B_3 = 141$	$B_4 = 162$	↑	↓	$C_3 = 113$	$C_4 = 134$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

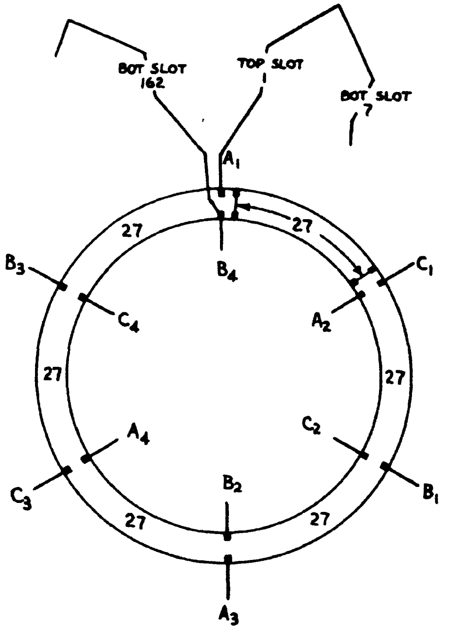


Fig. 7-15. Working Diagram for 168 slots, 26 poles, spp = 2 2/13

TABLE 7-16

Connection Table for 336 Slots, 26 Poles, spp=4 4/13; ($y=26$; $y_b=13$; $y_f=13$; $a=+2$; d=odd; P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-16

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	28	$\uparrow$	$A1_1$ = 1	$A1_2$ = 44	$\downarrow$	$\uparrow$	$B1_1$ = 113	$B1_2$ = 156	$\downarrow$	$\uparrow$	$C1_1$ = 57	$C1_2$ = 100	$\downarrow$
	28	$\downarrow$	$A2_1$ = 14	$A2_2$ = 57	$\uparrow$	$\downarrow$	$B2_1$ = 126	$B2_2$ = 169	$\uparrow$	$\downarrow$	$C2_1$ = 70	$C2_2$ = 113	$\uparrow$
	28	$\downarrow$	$A1_3$ = 169	$A1_4$ = 212	$\uparrow$	$\downarrow$	$B1_3$ = 281	$B1_4$ = 324	$\uparrow$	$\downarrow$	$C1_3$ = 225	$C1_4$ = 268	$\uparrow$
	28	$\uparrow$	$A2_3$ = 182	$A2_4$ = 225	$\downarrow$	$\uparrow$	$B2_3$ = 294	$B2_4$ = 1	$\downarrow$	$\uparrow$	$C2_3$ = 238	$C2_4$ = 281	$\downarrow$

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A2_3$ $A1_4 \rightarrow A2_4$	$A1_3$	$A1_3 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B2_3$ $B1_4 \rightarrow B2_4$	$B1_3$	$B1_3 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C2_3$ $C1_4 \rightarrow C2_4$	$C1_1$	$C1_1 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_4$	$A1_2 \rightarrow A2_2$ $A1_3 \rightarrow A2_3$	$A2_1 \rightarrow A2_4$	$A2_1 \rightarrow A2_4 \rightarrow B1_1 \rightarrow B1_4$
	$B1_1 \rightarrow B1_4$	$B1_2 \rightarrow B2_2$ $B1_3 \rightarrow B2_3$	$B2_1 \rightarrow B2_4$	$B2_1 \rightarrow B2_4 \rightarrow C1_2 \rightarrow C1_3$
	$C1_2 \rightarrow C1_3$	$C1_1 \rightarrow C2_1$ $C1_4 \rightarrow C2_4$	$C2_2 \rightarrow C2_3$	$C2_2 \rightarrow C2_3 \rightarrow A1_1 \rightarrow A1_4$

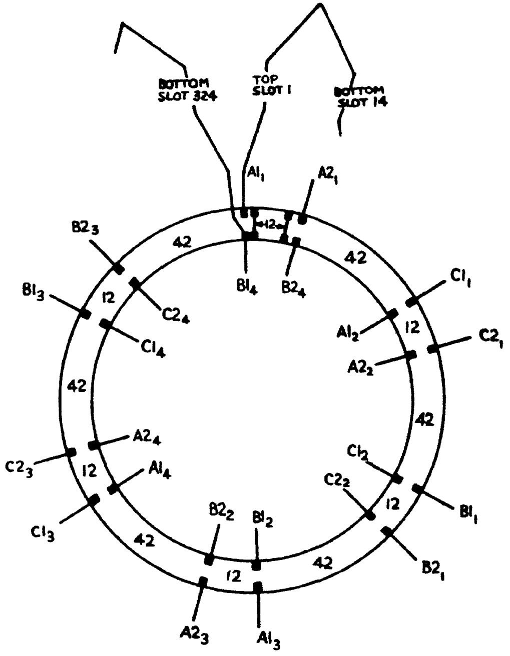


Fig. 7-16. Working Diagram for 336 slots, 26 poles, spp = 4 4/13

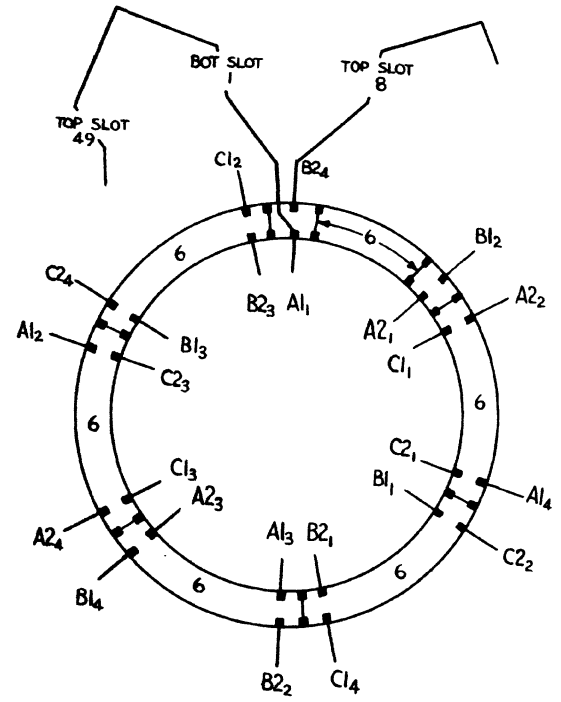


Fig. 7-17. Working Diagram for 54 slots, 8 poles, spp = 2 1/4

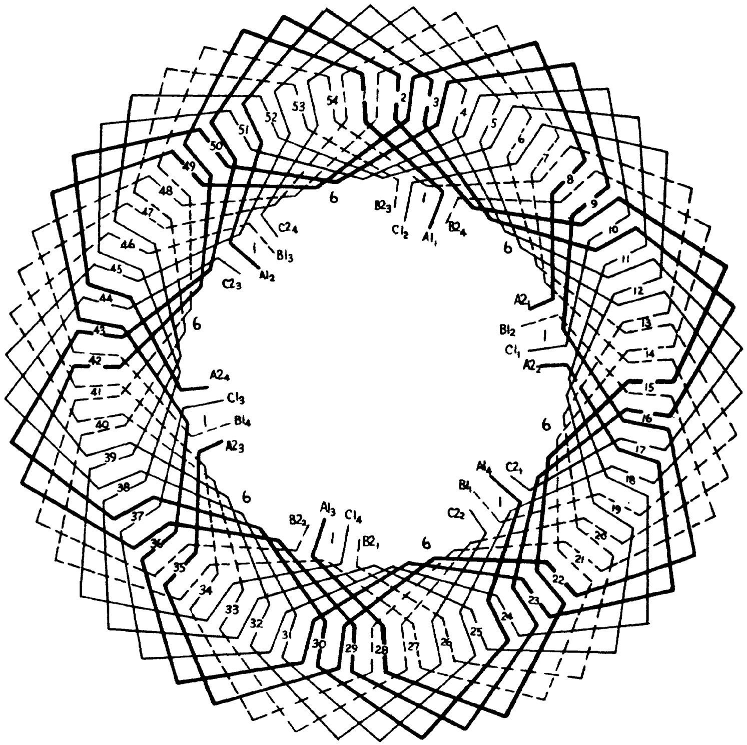


Fig. 7-17a. Fully developed diagram for 54 slots, 8 poles, spp = 2 1/4

TABLE 7-17

Connection Table for 54 Slots, 8 Poles, spp=2 1/4; $(y=13;\ y_f=6;\ y_f=7;\ a=-2;\ d=\text{even};\ P=\text{odd})$

REFERENCE WORKING DIAGRAM Fig. 7-17

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
4	5	↑	$A1_1 = 1$	$A1_2 = 51$	↓	↑	$B1_1 = 19$	$B1_2 = 15$	↓	↑	$C1_1 = 10$	$C1_2 = 6$	↓
	4	↓	$A2_1 = 8$	$A2_2 = 17$	↑	↓	$B2_1 = 26$	$B2_2 = 35$	↑	↓	$C2_1 = 17$	$C2_2 = 26$	↑
	5	↑	$A1_3 = 28$	$A1_4 = 24$	↓	↑	$B1_3 = 46$	$B1_4 = 42$	↓	↑	$C1_3 = 37$	$C1_4 = 33$	↓
	4	↓	$A2_3 = 35$	$A2_4 = 44$	↑	↓	$B2_3 = 53$	$B2_4 = 8$	↑	↓	$C2_3 = 44$	$C2_4 = 53$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_4$ $A1_3 \rightarrow A2_3$ $A1_4 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_4$ $B1_3 \rightarrow B2_3$ $B1_4 \rightarrow B2_4$	$B2_1$	$B2_1 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_4$ $C2_1 \rightarrow C1_1$ $C1_4 \rightarrow C2_2$	$C2_3$	$C2_3 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_3$	$A1_2 \rightarrow A2_4$ $A1_4 \rightarrow A2_2$	$A2_1 \rightarrow A2_3$	$A2_1 \rightarrow A2_3 \rightarrow B1_1 \rightarrow B1_3$
	$B1_1 \rightarrow B1_3$	$B1_2 \rightarrow B2_4$ $B1_4 \rightarrow B2_2$	$B2_1 \rightarrow B2_3$	$B2_1 \rightarrow B2_3 \rightarrow C1_1 \rightarrow C1_3$
	$C1_1 \rightarrow C1_3$	$C1_2 \rightarrow C2_4$ $C1_4 \rightarrow C2_2$	$C2_1 \rightarrow C2_3$	$C2_1 \rightarrow C2_3 \rightarrow A1_1 \rightarrow A1_3$

TABLE 7-18

Connection Table for 81 Slots, 12 Poles, spp=2 1/4; ($y=13$; $y_b=6$; $y_f=7$; $a=-2$; d=even; P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-18

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
6	5	↑	$A1_1$ = 1	$A1_2$ = 24	↓	↑	$B1_1$ = 19	$B1_2$ = 42	↓	↑	$C1_1$ = 10	$C1_2$ = 33	↓
	4	↓	$A2_1$ = 8	$A2_2$ = 44	↑	↓	$B2_1$ = 26	$B2_2$ = 62	↑	↓	$C2_1$ = 17	$C2_2$ = 53	↑
	5	↑	$A1_3$ = 28	$A1_4$ = 51	↓	↑	$B1_3$ = 46	$B1_4$ = 69	↓	↑	$C1_3$ = 37	$C1_4$ = 60	↓
	4	↓	$A2_3$ = 35	$A2_4$ = 71	↑	↓	$B2_3$ = 53	$B2_4$ = 8	↑	↓	$C2_3$ = 44	$C2_4$ = 80	↑
	5	↑	$A1_5$ = 55	$A1_6$ = 78	↓	↑	$B1_5$ = 73	$B1_6$ = 15	↓	↑	$C1_5$ = 64	$C1_6$ = 6	↓
	4	↓	$A2_5$ = 62	$A2_6$ = 17	↑	↓	$B2_5$ = 80	$B2_6$ = 35	↑	↓	$C2_5$ = 71	$C2_6$ = 26	↑

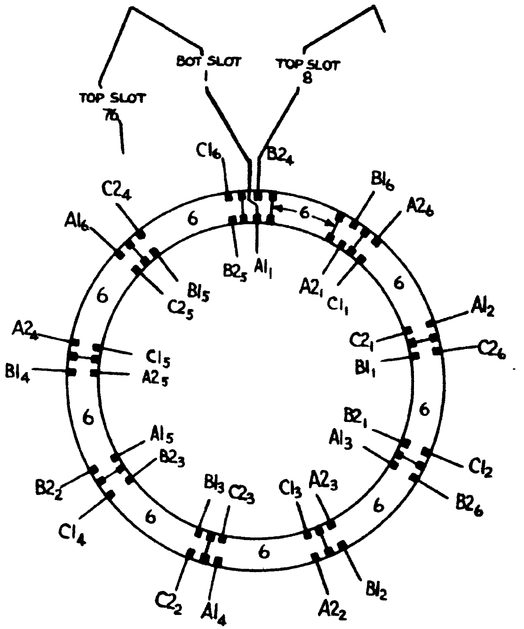


Fig. 7-18. Working Diagram for 81 slots, 12 poles, spp = 2 1/4

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_6$ $A2_5 \rightarrow A1_5$ $A1_6 \rightarrow A2_4$ $A2_3 \rightarrow A1_3$ $A1_4 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_6$ $B2_5 \rightarrow B1_5$ $B1_6 \rightarrow B2_4$ $B2_3 \rightarrow B1_3$ $B1_4 \rightarrow B2_2$	$B2_1$	$B2_1 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_6$ $C2_5 \rightarrow C1_5$ $C1_6 \rightarrow C2_4$ $C1_1 \rightarrow C2_1$ $C1_4 \rightarrow C2_2$	$C2_3$	$C2_3 \rightarrow A1_1$
3	$A1_1 \rightarrow A1_3 \rightarrow A1_5$	$A1_2 \rightarrow A2_6$ $A1_6 \rightarrow A2_4$ $A1_4 \rightarrow A2_2$	$A2_1 \rightarrow A2_3 \rightarrow A2_5$	$A2_1 \rightarrow A2_3 \rightarrow A2_5 \rightarrow B1_1 \rightarrow B1_3 \rightarrow B1_5$
	$B1_1 \rightarrow B1_3 \rightarrow B1_5$	$B1_2 \rightarrow B2_6$ $B1_6 \rightarrow B2_4$ $B1_4 \rightarrow B2_2$	$B2_1 \rightarrow B2_3 \rightarrow B2_5$	$B2_1 \rightarrow B2_3 \rightarrow B2_5 \rightarrow C1_1 \rightarrow C1_3 \rightarrow C1_5$
	$C1_1 \rightarrow C1_3 \rightarrow C1_5$	$C1_2 \rightarrow C2_6$ $C1_6 \rightarrow C2_4$ $C1_4 \rightarrow C2_2$	$C2_1 \rightarrow C2_3 \rightarrow C2_5$	$C2_1 \rightarrow C2_3 \rightarrow C2_5 \rightarrow A1_1 \rightarrow A1_3 \rightarrow A1_5$

TABLE 7-19

Connection Table for 108 Slots, 16 Poles, spp=2 1/4;($y=13$; $y_b=6$; $y_f=7$; $a=-2$; d=even; P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-19

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
8	5	↑	$A1_1$ = 1	$A1_2$ = 51	↓	↑	$B1_1$ = 19	$B1_2$ = 69	↓	↑	$C1_1$ = 10	$C1_2$ = 60	↓
	4	↓	$A2_1$ = 8	$A2_2$ = 71	↑	↓	$B2_1$ = 26	$B2_2$ = 89	↑	↓	$C2_1$ = 17	$C2_2$ = 80	↑
	5	↑	$A1_3$ = 28	$A1_4$ = 78	↓	↑	$B1_3$ = 46	$B1_4$ = 96	↓	↑	$C1_3$ = 37	$C1_4$ = 87	↓
	4	↓	$A2_3$ = 35	$A2_4$ = 98	↑	↓	$B2_3$ = 53	$B2_4$ = 8	↑	↓	$C2_3$ = 44	$C2_4$ = 107	↑
	5	↑	$A1_5$ = 55	$A1_6$ = 105	↓	↑	$B1_5$ = 73	$B1_6$ = 15	↓	↑	$C1_5$ = 64	$C1_6$ = 6	↓
	4	↓	$A2_5$ = 62	$A2_6$ = 17	↑	↓	$B2_5$ = 80	$B2_6$ = 35	↑	↓	$C2_5$ = 71	$C2_6$ = 26	↑
	5	↑	$A1_7$ = 82	$A1_8$ = 24	↓	↑	$B1_7$ = 100	$B1_8$ = 42	↓	↑	$C1_7$ = 91	$C1_8$ = 33	↓
	4	↓	$A2_7$ = 89	$A2_8$ = 44	↑	↓	$B2_7$ = 107	$B2_8$ = 62	↑	↓	$C2_7$ = 98	$C2_8$ = 53	↑

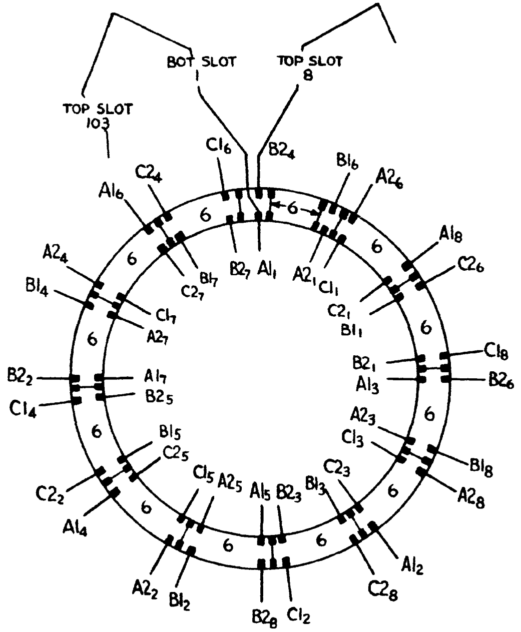


Fig. 7-19. Working Diagram for 108 slots, 16 poles, spp = 2 1/4

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_7 \to A2_8$ $A2_7 \to A1_7$ $A1_8 \to A2_6$ $A2_5 \to A1_5$ $A1_6 \to A2_4$ $A2_3 \to A1_3$ $A1_4 \to A2_2$	$A2_1$	$A2_1 \to C1_3$
	$B1_5$	$B1_2 \to B2_8$ $B2_7 \to B1_7$ $B1_8 \to B2_6$ $B2_1 \to B1_1$ $B1_6 \to B2_4$ $B2_3 \to B1_3$ $B1_4 \to B2_2$	$B2_5$	$B2_5 \to A1_1$
	$C1_3$	$C1_2 \to C2_8$ $C2_7 \to C1_7$ $C1_8 \to C2_6$ $C2_1 \to C1_1$ $C1_6 \to C2_4$ $C2_5 \to C1_5$ $C1_4 \to C2_2$	$C2_3$	$C2_3 \to B1_5$
2	$A1_1 \to A1_5$	$A1_2 \to A2_8$ $A2_7 \to A1_7$ $A1_8 \to A2_6$ $A1_6 \to A2_4$ $A2_3 \to A1_3$ $A1_4 \to A2_2$	$A2_5 \to A2_1$	$A2_5 \to A2_1 \to B1_1 \to B1_5$
	$B1_1 \to B1_5$	$B1_2 \to B2_8$ $B2_7 \to B1_7$ $B1_8 \to B2_6$ $B1_6 \to B2_4$ $B2_3 \to B1_3$ $B1_4 \to B2_2$	$B2_5 \to B2_1$	$B2_5 \to B2_1 \to C1_3 \to C1_7$
	$C1_3 \to C1_7$	$C1_2 \to C2_8$ $C2_5 \to C1_5$ $C1_8 \to C2_6$ $C1_6 \to C2_4$ $C2_1 \to C1_1$ $C1_4 \to C2_2$	$C2_7 \to C2_3$	$C2_7 \to C2_3 \to A1_1 \to A1_5$
4	$A1_1 \to A1_3 \to$ $A1_5 \to A1_7$	-	$A2_1 \to A2_3 \to$ $A2_5 \to A2_7$	$A2_1 \to A2_3 \to A2_5 \to A2_7 \to$ $B1_1 \to B1_3 \to B1_5 \to B1_7$
	$B1_1 \to B1_3 \to$ $B1_5 \to B1_7$	-	$B2_1 \to B2_3 \to$ $B2_5 \to B2_7$	$B2_1 \to B2_3 \to B2_5 \to B2_7 \to$ $C1_1 \to C1_3 \to C1_5 \to C1_7$
	$C1_1 \to C1_3 \to$ $C1_5 \to C1_7$	-	$C2_1 \to C2_3 \to$ $C2_5 \to C2_7$	$C2_1 \to C2_3 \to C2_5 \to C2_7 \to$ $A1_1 \to A1_3 \to A1_5 \to A1_7$

TABLE 7-20

Connection Table for 126 Slots, 8 Poles, spp=5 1/4; (y 31; y_b=15; y_f=16; a=-2;' d=even; P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-20

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
4	11	↑	$A1_1$ = 1	$A1_2$ = 54	↓	↑	$B1_1$ = 43	$B1_2$ = 96	↓	↑	$C1_1$ = 22	$C1_2$ = 75	↓
	10	↓	$A2_1$ = 17	$A2_2$ = 101	↑	↓	$B2_1$ = 59	$B2_2$ = 17	↑	↓	$C2_1$ = 38	$C2_2$ = 122	↑
	11	↑	$A1_3$ = 64	$A1_4$ = 117	↓	↑	$B1_3$ = 106	$B1_4$ = 33	↓	↑	$C1_3$ = 85	$C1_4$ = 12	↓
	10	↓	$A2_3$ = 80	$A2_4$ = 38	↑	↓	$B2_3$ = 122	$B2_4$ = 80	↑	↓	$C2_3$ = 101	$C2_4$ = 59	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_4$ $A1_3 \rightarrow A2_3$ $A1_4 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_4$ $B1_3 \rightarrow B2_3$ $B1_4 \rightarrow B2_2$	$B2_1$	$B2_1 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_4$ $C1_1 \rightarrow C2_1$ $C1_4 \rightarrow C2_2$	$C2_3$	$C2_3 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_3$	$A1_2 \rightarrow A2_4$ $A1_4 \rightarrow A2_2$	$A2_1 \rightarrow A2_3$	$A2_1 \rightarrow A2_3 \rightarrow B1_1 \rightarrow B1_3$
	$B1_1 \rightarrow B1_3$	$B1_2 \rightarrow B2_4$ $B1_4 \rightarrow B2_2$	$B2_1 \rightarrow B2_3$	$B2_1 \rightarrow B2_3 \rightarrow C1_1 \rightarrow C1_3$
	$C1_1 \rightarrow C1_3$	$C1_2 \rightarrow C2_4$ $C1_4 \rightarrow C2_2$	$C2_1 \rightarrow C2_3$	$C2_1 \rightarrow C2_3 \rightarrow A1_1 \rightarrow A1_3$

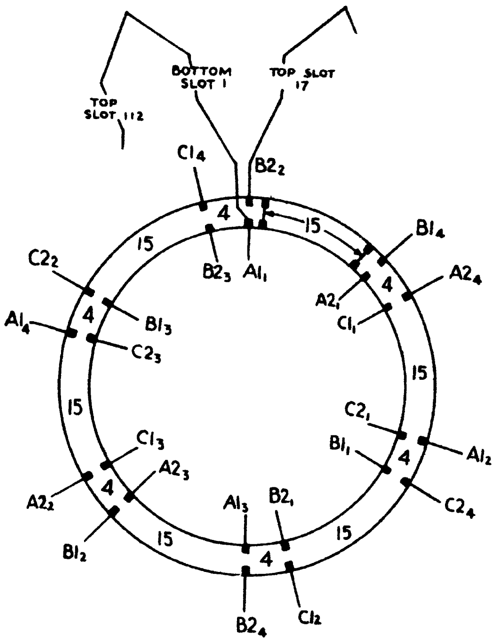


Fig. 7-20. Working Diagram for 126 slots, 8 poles, spp = 5 1/4

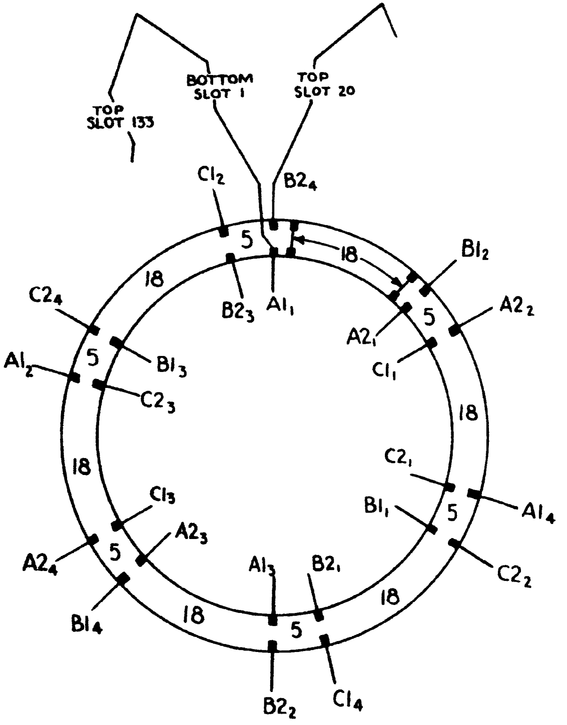


Fig. 7-21. Working Diagram for 150 slots, 8 poles, spp = 6 1/4

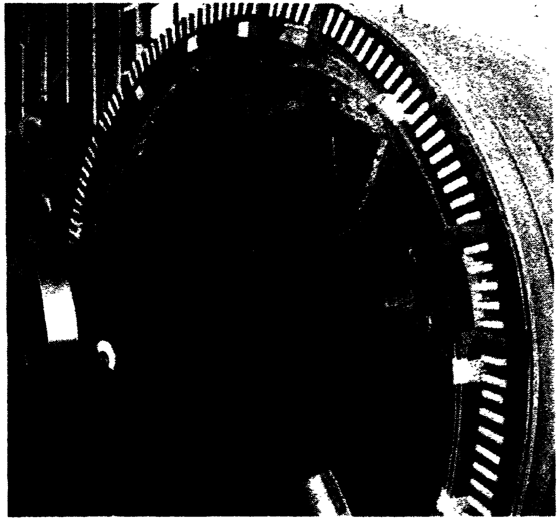


Fig. 7-21a. Photograph of the connection end of the winding shown by working Diagram Fig. 7-21. The winding is connected single-circuit delta, according to Connection Table 7-21.

TABLE 7-21

Connection Table for 150 Slots, 8 Poles, spp=6 1/4; $(y=37;\ y_b=18;\ y_f=19;\ a=-2;\ d=\text{even};\ P=\text{odd})$

REFERENCE WORKING DIAGRAM Fig. 7-21

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	13	↑	$A1_1 = 1$	$A1_2 = 139$	↓	↑	$B1_1 = 51$	$B1_2 = 39$	↓	↑	$C1_1 = 26$	$C1_2 = 14$	↓
	12	↓	$A2_1 = 20$	$A2_2 = 45$	↑	↓	$B2_1 = 70$	$B2_2 = 95$	↑	↓	$C2_1 = 45$	$C2_2 = 70$	↑
	13	↑	$A1_3 = 76$	$A1_4 = 64$	↓	↑	$B1_3 = 126$	$B1_4 = 114$	↓	↑	$C1_3 = 101$	$C1_4 = 89$	↓
	12	↓	$A2_3 = 95$	$A2_4 = 120$	↑	↓	$B2_3 = 145$	$B2_4 = 20$	↑	↓	$C2_3 = 120$	$C2_4 = 145$	↑

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_4$ $A1_3 \rightarrow A2_3$ $A1_4 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_4$ $B1_3 \rightarrow B2_3$ $B1_4 \rightarrow B2_2$	$B2_1$	$B2_1 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_4$ $C1_1 \rightarrow C2_1$ $C1_4 \rightarrow C2_2$	$C2_3$	$C2_3 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_3$	$A1_2 \rightarrow A2_4$ $A1_4 \rightarrow A2_2$	$A2_1 \rightarrow A2_3$	$A2_1 \rightarrow A2_3 \rightarrow B1_1 \rightarrow B1_3$
	$B1_1 \rightarrow B1_3$	$B1_2 \rightarrow B2_4$ $B1_4 \rightarrow B2_2$	$B2_1 \rightarrow B2_3$	$B2_1 \rightarrow B2_3 \rightarrow C1_1 \rightarrow C1_3$
	$C1_1 \rightarrow C1_3$	$C1_2 \rightarrow C2_4$ $C1_4 \rightarrow C2_2$	$C2_1 \rightarrow C2_3$	$C2_1 \rightarrow C2_3 \rightarrow A1_1 \rightarrow A1_3$

TABLE 7-22

Connection Table for 90 Slots, 8 Poles, spp= 3 3/4; ($y=22$; $y_b=11$; $y_f=11$; $a=-2$; d=even; P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-22

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
4	8	↑	$A1_1$ = 1	$A1_2$ = 16	↓	↑	$B1_1$ = 31	$B1_2$ = 46	↓	↑	$C1_1$ = 16	$C1_2$ = 31	↓
	7	↓	$A2_1$ = 35	$A2_2$ = 72	↑	↓	$B2_1$ = 20	$B2_2$ = 57	↑	↓	$C2_1$ = 5	$C2_2$ = 42	↑
	8	↑	$A1_3$ = 46	$A1_4$ = 61	↓	↑	$B1_3$ = 76	$B1_4$ = 1	↓	↑	$C1_3$ = 61	$C1_4$ = 76	↓
	7	↓	$A2_3$ = 80	$A2_4$ = 27	↑	↓	$B2_3$ = 65	$B2_4$ = 12	↑	↓	$C2_3$ = 50	$C2_4$ = 87	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_4$ $A2_3 \rightarrow A1_3$ $A1_4 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B1_3$ $B1_4 \rightarrow B2_4$	$B2_3$	$B2_3 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_2$ $C2_3 \rightarrow C1_1$ $C1_4 \rightarrow C2_4$	$C2_1$	$C2_1 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_3$	$A1_2 \rightarrow A2_4$ $A1_4 \rightarrow A2_2$	$A2_3 \rightarrow A2_1$	$A2_3 \rightarrow A2_1 \rightarrow B1_1 \rightarrow B1_3$
	$B1_1 \rightarrow B1_3$	$B1_2 \rightarrow B2_2$ $B1_4 \rightarrow B2_4$	$B2_1 \rightarrow B2_3$	$B2_1 \rightarrow B2_3 \rightarrow C1_1 \rightarrow C1_3$
	$C1_1 \rightarrow C1_3$	$C1_2 \rightarrow C2_2$ $C1_4 \rightarrow C2_4$	$C2_1 \rightarrow C2_3$	$C2_1 \rightarrow C2_3 \rightarrow A1_1 \rightarrow A1_3$

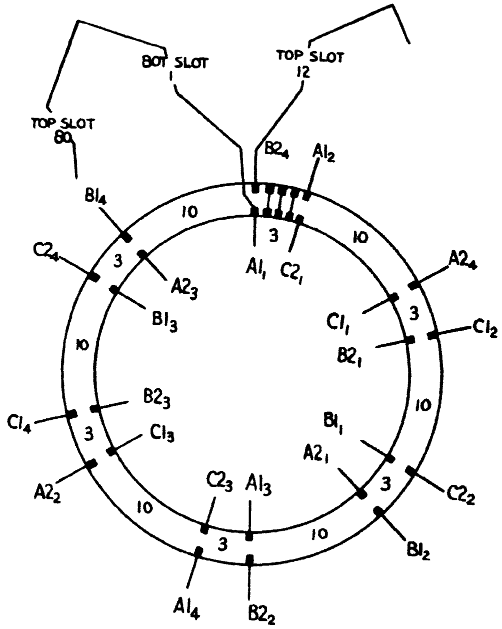


Fig. 7-22. Working Diagram for 90 slots, 8 poles, spp = 3 3/4

TABLE 7-23

Connection Table for 135 Slots, 12 Poles, spp=3 3/4;(y=22; y_b=11; y_f=11; a=-2; d=even; P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-23

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
6	8	↑	$A1_1$ = 1	$A1_2$ = 106	↓	↑	$B1_1$ = 31	$B1_2$ = 1	↓	↑	$C1_1$ = 16	$C1_2$ = 121	↓
	7	↓	$A2_1$ = 35	$A2_2$ = 27	↑	↓	$B2_1$ = 20	$B2_2$ = 12	↑	↓	$C2_1$ = 5	$C2_2$ = 132	↑
	8	↑	$A1_3$ = 46	$A1_4$ = 16	↓	↑	$B1_3$ = 76	$B1_4$ = 46	↓	↑	$C1_3$ = 61	$C1_4$ = 31	↓
	7	↓	$A2_3$ = 80	$A2_4$ = 72	↑	↓	$B2_3$ = 65	$B2_4$ = 57	↑	↓	$C2_3$ = 50	$C2_4$ = 42	↑
	8	↑	$A1_5$ = 91	$A1_6$ = 61	↓	↑	$B1_5$ = 121	$B1_6$ = 91	↓	↑	$C1_5$ = 106	$C1_6$ = 76	↓
	7	↓	$A2_5$ = 125	$A2_6$ = 117	↑	↓	$B2_5$ = 110	$B2_6$ = 102	↑	↓	$C2_5$ = 95	$C2_6$ = 87	↑

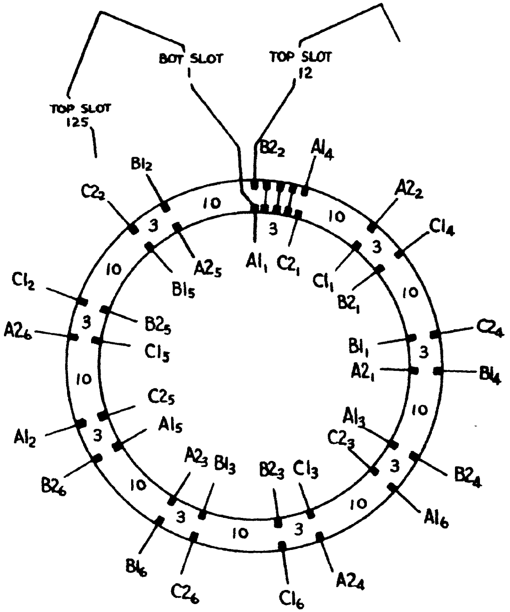


Fig. 7-23. Working Diagram for 135 slots, 12 poles, spp = 3 3/4

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_6$ $A2_5 \rightarrow A1_5$ $A1_6 \rightarrow A2_4$ $A2_3 \rightarrow A1_3$ $A1_4 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B1_5$ $B1_6 \rightarrow B2_6$ $B2_5 \rightarrow B1_3$ $B1_4 \rightarrow B2_4$	$B2_3$	$B2_3 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_2$ $C2_3 \rightarrow C1_1$ $C2_1 \rightarrow C1_5$ $C1_6 \rightarrow C2_6$ $C1_4 \rightarrow C2_4$	$C2_5$	$C2_5 \rightarrow A1_1$
3	$A1_1 \rightarrow A1_3 \rightarrow A1_5$	$A1_2 \rightarrow A2_6$ $A1_6 \rightarrow A2_4$ $A1_4 \rightarrow A2_2$	$A2_1 \rightarrow A2_3 \rightarrow A2_5$	$A2_1 \rightarrow A2_3 \rightarrow A2_5 \rightarrow B1_1 \rightarrow B1_3 \rightarrow B1_5$
	$B1_1 \rightarrow B1_3 \rightarrow B1_5$	$B1_2 \rightarrow B2_2$ $B1_6 \rightarrow B2_6$ $B1_4 \rightarrow B2_4$	$B2_1 \rightarrow B2_3 \rightarrow B2_5$	$B2_1 \rightarrow B2_3 \rightarrow B2_5 \rightarrow C1_1 \rightarrow C1_3 \rightarrow C1_5$
	$C1_1 \rightarrow C1_3 \rightarrow C1_5$	$C1_2 \rightarrow C2_2$ $C1_6 \rightarrow C2_6$ $C1_4 \rightarrow C2_4$	$C2_1 \rightarrow C2_3 \rightarrow C2_5$	$C2_1 \rightarrow C2_3 \rightarrow C2_5 \rightarrow A1_1 \rightarrow A1_3 \rightarrow A1_5$

TABLE 7-24

Connection Table for 180 Slots, 16 Poles, spp=3 3/4; ($y=22$; $y_b=11$; $y_f=11$; $a=-2$; d=even; P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-24

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
8	8	↑	$A1_1$ = 1	$A1_2$ = 16	↓	↑	$B1_1$ = 31	$B1_2$ = 46	↓	↑	$C1_1$ = 16	$C1_2$ = 31	↓
	7	↓	$A2_1$ = 35	$A2_2$ = 72	↑	↓	$B2_1$ = 20	$B2_2$ = 57	↑	↓	$C2_1$ = 5	$C2_2$ = 42	↑
	8	↑	$A1_3$ = 46	$A1_4$ = 61	↓	↑	$B1_3$ = 76	$B1_4$ = 91	↓	↑	$C1_3$ = 61	$C1_4$ = 76	↓
	7	↓	$A2_3$ = 80	$A2_4$ = 117	↑	↓	$B2_3$ = 65	$B2_4$ = 102	↑	↓	$C2_3$ = 50	$C2_4$ = 87	↑
	8	↑	$A1_5$ = 91	$A1_6$ = 106	↓	↑	$B1_5$ = 121	$B1_6$ = 136	↓	↑	$C1_5$ = 106	$C1_6$ = 121	↓
	7	↓	$A2_5$ = 125	$A2_6$ = 162	↑	↓	$B2_5$ = 110	$B2_6$ = 147	↑	↓	$C2_5$ = 95	$C2_6$ = 132	↑
	8	↑	$A1_7$ = 136	$A1_8$ = 151	↓	↑	$B1_7$ = 166	$B1_8$ = 1	↓	↑	$C1_7$ = 151	$C1_8$ = 166	↓
	7	↓	$A2_7$ = 170	$A2_8$ = 27	↑	↓	$B2_7$ = 155	$B2_8$ = 12	↑	↓	$C2_7$ = 140	$C2_8$ = 177	↑

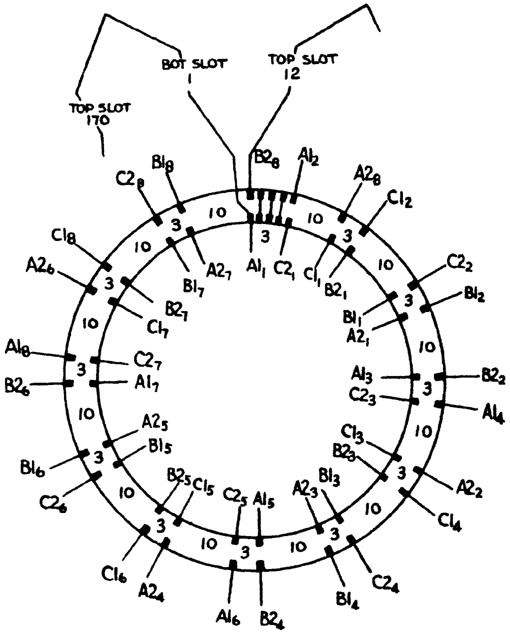


Fig. 7-24. Working Diagram for 180 slots, 16 poles, spp = 3 3/4

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_8\ A2_7 \rightarrow A1_7\ A1_8 \rightarrow A2_6\ A2_5 \rightarrow A1_5$ $A1_6 \rightarrow A2_4\ A2_3 \rightarrow A1_3\ A1_4 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow C1_3$
	$B1_5$	$B1_2 \rightarrow B2_2\ B2_1 \rightarrow B1_7\ B1_8 \rightarrow B2_8\ B2_5 \rightarrow B1_3$ $B1_6 \rightarrow B2_6\ B2_3 \rightarrow B1_1\ B1_4 \rightarrow B2_4$	$B2_7$	$B2_7 \rightarrow A1_1$
	$C1_3$	$C1_2 \rightarrow C2_2\ C2_1 \rightarrow C1_7\ C1_8 \rightarrow C2_8\ C2_7 \rightarrow C1_5$ $C1_6 \rightarrow C2_6\ C2_3 \rightarrow C1_1\ C1_4 \rightarrow C2_4$	$C2_5$	$C2_5 \rightarrow B1_5$
2	$A1_1 \rightarrow A1_5$	$A1_2 \rightarrow A2_8\ A2_7 \rightarrow A1_7\ A1_8 \rightarrow A2_6\ A1_6 \rightarrow A2_4$ $A2_3 \rightarrow A1_3\ A1_4 \rightarrow A2_2$	$A2_1 \rightarrow A2_5$	$A2_1 \rightarrow A2_5 \rightarrow B1_1 \rightarrow B1_5$
	$B1_1 \rightarrow B1_5$	$B1_2 \rightarrow B2_2\ B2_1 \rightarrow B1_7\ B1_8 \rightarrow B2_8\ B1_6 \rightarrow B2_6$ $B2_5 \rightarrow B1_3\ B1_4 \rightarrow B2_4$	$B2_7 \rightarrow B2_3$	$B2_7 \rightarrow B2_3 \rightarrow C1_3 \rightarrow C1_7$
	$C1_3 \rightarrow C1_7$	$C1_4 \rightarrow C2_4\ C2_3 \rightarrow C1_1\ C1_2 \rightarrow C2_2\ C1_8 \rightarrow C2_8$ $C2_7 \rightarrow C1_5\ C1_6 \rightarrow C2_6$	$C2_1 \rightarrow C2_5$	$C2_1 \rightarrow C2_5 \rightarrow A1_1 \rightarrow A1_5$
4	$A1_1 \rightarrow A1_3 \rightarrow$ $A1_5 \rightarrow A1_7$	$A1_2 \rightarrow A2_8\ A1_4 \rightarrow A2_2\ A1_6 \rightarrow A2_4\ A1_8 \rightarrow A2_6$	$A2_1 \rightarrow A2_3 \rightarrow$ $A2_5 \rightarrow A2_7$	$A2_1 \rightarrow A2_3 \rightarrow A2_5 \rightarrow A2_7 \rightarrow$ $B1_1 \rightarrow B1_3 \rightarrow B1_5 \rightarrow B1_7$
	$B1_1 \rightarrow B1_3 \rightarrow$ $B1_5 \rightarrow B1_7$	$B1_2 \rightarrow B2_2\ B1_4 \rightarrow B2_4\ B1_6 \rightarrow B2_6\ B1_8 \rightarrow B2_8$	$B2_1 \rightarrow B2_3 \rightarrow$ $B2_5 \rightarrow B2_7$	$B2_1 \rightarrow B2_3 \rightarrow B2_5 \rightarrow B2_7 \rightarrow$ $C1_1 \rightarrow C1_3 \rightarrow C1_5 \rightarrow C1_7$
	$C1_1 \rightarrow C1_3 \rightarrow$ $C1_5 \rightarrow C1_7$	$C1_2 \rightarrow C2_2\ C1_4 \rightarrow C2_4\ C1_6 \rightarrow C2_6\ C1_8 \rightarrow C2_8$	$C2_1 \rightarrow C2_3 \rightarrow$ $C2_5 \rightarrow C2_7$	$C2_1 \rightarrow C2_3 \rightarrow C2_5 \rightarrow C2_7 \rightarrow$ $A1_1 \rightarrow A1_3 \rightarrow A1_5 \rightarrow A1_7$

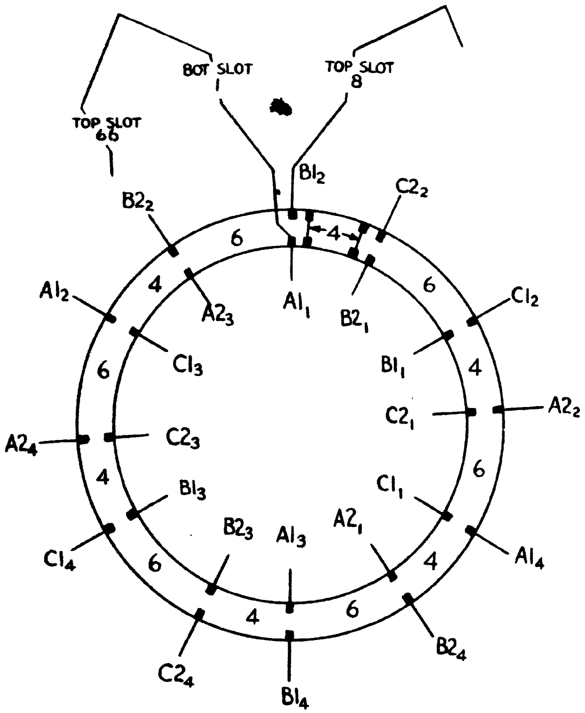


Fig. 7-25. Working Diagram for 72 slots, 10 poles, spp = 2 2/5

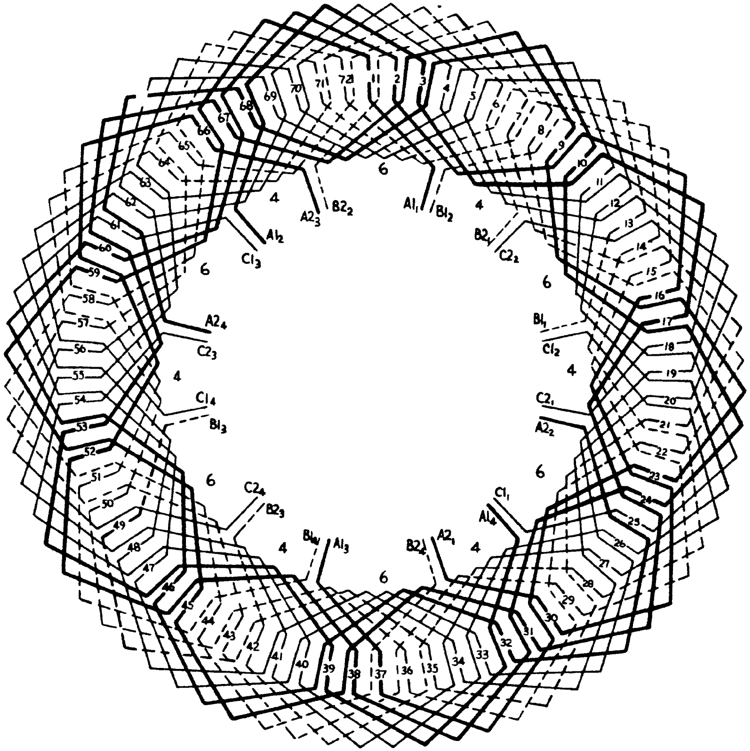


Fig. 7-25a. Fully developed diagram for 72 slots, 10 poles, spp = 2 2/5

TABLE 7-25

Connection Table for 72 Slots, 10 Poles, spp=2 2/5; ($y=14$; $y_b=7$; $y_f=7$; $a=-2$; d=odd; P=even)

REFERENCE WORKING DIAGRAM Fig. 7-25

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
4	6	↑	$A1_1 = 1$	$A1_2 = 68$	↓	↑	$B1_1 = 13$	$B1_2 = 8$	↓	↑	$C1_1 = 25$	$C1_2 = 20$	↓
	6	↑	$A2_1 = 30$	$A2_2 = 25$	↓	↓	$B2_1 = 6$	$B2_2 = 1$	↑	↓	$C2_1 = 18$	$C2_2 = 13$	↑
	6	↓	$A1_3 = 37$	$A1_4 = 32$	↑	↓	$B1_3 = 49$	$B1_4 = 44$	↑	↓	$C1_3 = 61$	$C1_4 = 56$	↑
	6	↓	$A2_3 = 66$	$A2_4 = 61$	↑	↑	$B2_3 = 42$	$B2_4 = 37$	↓	↑	$C2_3 = 54$	$C2_4 = 49$	↓

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_4$ $A2_1 \rightarrow A2_3$ $A1_4 \rightarrow A2_2$	$A1_3$	$A1_3 \rightarrow B1_3$
	$B1_3$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$	$B1_1$	$B1_1 \rightarrow C1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C2_3$ $C1_4 \rightarrow C2_4$	$C1_3$	$C1_3 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_4$	$A1_2 \rightarrow A2_4$ $A1_3 \rightarrow A2_1$	$A2_2 \rightarrow A2_3$	$A2_2 \rightarrow A2_3 \rightarrow B1_3 \rightarrow B1_2$
	$B1_3 \rightarrow B1_2$	$B1_1 \rightarrow B2_1$ $B1_4 \rightarrow B2_4$	$B2_3 \rightarrow B2_2$	$B2_3 \rightarrow B2_2 \rightarrow C1_1 \rightarrow C1_4$
	$C1_1 \rightarrow C1_4$	$C1_2 \rightarrow C2_2$ $C1_3 \rightarrow C2_3$	$C2_4 \rightarrow C2_1$	$C2_4 \rightarrow C2_1 \rightarrow A1_1 \rightarrow A1_4$

TABLE 7-26

Connection Table for 144 Slots, 20 Poles, spp=2 2/5; ($y=14$; $y_b=7$; $y_f=7$; $a=-2$; d=odd; P=even)

REFERENCE WORKING DIAGRAM Fig. 7-26

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
8	6	↑	$A1_1 = 1$	$A1_2 = 68$	↓	↑	$B1_1 = 13$	$B1_2 = 80$	↓	↑	$C1_1 = 25$	$C1_2 = 92$	↓
	6	↑	$A2_1 = 30$	$A2_2 = 97$	↓	↓	$B2_1 = 6$	$B2_2 = 73$	↑	↓	$C2_1 = 18$	$C2_2 = 85$	↑
	6	↓	$A1_3 = 37$	$A1_4 = 104$	↑	↓	$B1_3 = 49$	$B1_4 = 116$	↑	↓	$C1_3 = 61$	$C1_4 = 128$	↑
	6	↓	$A2_3 = 66$	$A2_4 = 133$	↑	↑	$B2_3 = 42$	$B2_4 = 109$	↓	↑	$C2_3 = 54$	$C2_4 = 121$	↓
	6	↑	$A1_5 = 73$	$A1_6 = 140$	↓	↑	$B1_5 = 85$	$B1_6 = 8$	↓	↑	$C1_5 = 97$	$C1_6 = 20$	↓
	6	↑	$A2_5 = 102$	$A2_6 = 25$	↓	↓	$B2_5 = 78$	$B2_6 = 1$	↑	↓	$C2_5 = 90$	$C2_6 = 13$	↑
	6	↓	$A1_7 = 109$	$A1_8 = 32$	↑	↓	$B1_7 = 121$	$B1_8 = 44$	↑	↓	$C1_7 = 133$	$C1_8 = 56$	↑
	6	↓	$A2_7 = 138$	$A2_8 = 61$	↑	↑	$B2_7 = 114$	$B2_8 = 37$	↓	↑	$C2_7 = 126$	$C2_8 = 49$	↓

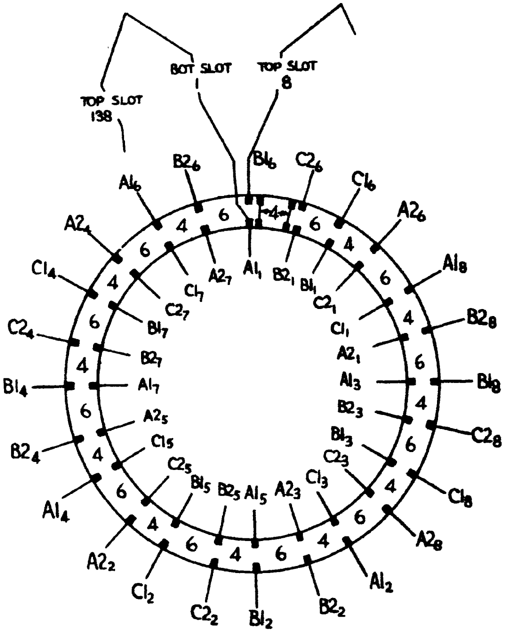


Fig. 7-26. Working Diagram for 144 slots, 20 poles, spp = 2 2/5

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_8$ $A2_7 \rightarrow A2_5$ $A2_6 \rightarrow A1_8$ $A1_7 \rightarrow A1_5$ $A1_6 \rightarrow A2_4$ $A2_3 \rightarrow A2_1$ $A2_2 \rightarrow A1_4$	$A1_3$	$A1_3 \rightarrow B1_3$
	$B1_3$	$B1_4 \rightarrow B2_4$ $B2_3 \rightarrow B2_1$ $B2_2 \rightarrow B1_2$ $B1_1 \rightarrow B1_7$ $B1_8 \rightarrow B2_8$ $B2_7 \rightarrow B2_5$ $B2_6 \rightarrow B1_6$	$B1_5$	$B1_5 \rightarrow C1_5$
	$C1_5$	$C1_6 \rightarrow C2_6$ $C2_5 \rightarrow C2_3$ $C2_4 \rightarrow C1_4$ $C1_3 \rightarrow C1_1$ $C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C2_7$ $C2_8 \rightarrow C1_8$	$C1_7$	$C1_7 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_5$	$A1_2 \rightarrow A2_8$ $A2_7 \rightarrow A2_5$ $A2_6 \rightarrow A1_8$ $A1_6 \rightarrow A2_4$ $A2_3 \rightarrow A2_1$ $A2_2 \rightarrow A1_4$	$A1_3 \rightarrow A1_7$	$A1_3 \rightarrow A1_7 \rightarrow B1_3 \rightarrow B1_7$
	$B1_3 \rightarrow B1_7$	$B1_4 \rightarrow B2_4$ $B2_3 \rightarrow B2_1$ $B2_2 \rightarrow B1_2$ $B1_8 \rightarrow B2_8$ $B2_7 \rightarrow B2_5$ $B2_6 \rightarrow B1_6$	$B1_1 \rightarrow B1_5$	$B1_1 \rightarrow B1_5 \rightarrow C1_1 \rightarrow C1_5$
	$C1_3 \rightarrow C1_5$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C2_7$ $C2_8 \rightarrow C1_8$ $C1_6 \rightarrow C2_6$ $C2_5 \rightarrow C2_3$ $C2_4 \rightarrow C1_4$	$C1_3 \rightarrow C1_7$	$C1_3 \rightarrow C1_7 \rightarrow A1_1 \rightarrow A1_5$
4	$A1_1 \rightarrow A1_4 \rightarrow$ $A1_5 \rightarrow A1_8$	$A1_2 \rightarrow A2_8$ $A1_3 \rightarrow A2_1$ $A1_6 \rightarrow A2_4$ $A1_7 \rightarrow A2_5$	$A2_2 \rightarrow A2_3 \rightarrow$ $A2_6 \rightarrow A2_7$	$A2_2 \rightarrow A2_3 \rightarrow A2_6 \rightarrow A2_7 \rightarrow$ $B1_2 \rightarrow B1_3 \rightarrow B1_6 \rightarrow B1_7$
	$B1_2 \rightarrow B1_3 \rightarrow$ $B1_6 \rightarrow B1_7$	$B1_4 \rightarrow B2_4$ $B1_1 \rightarrow B2_1$ $B1_5 \rightarrow B2_5$ $B1_8 \rightarrow B2_8$	$B2_2 \rightarrow B2_3 \rightarrow$ $B2_6 \rightarrow B2_7$	$B2_2 \rightarrow B2_3 \rightarrow B2_6 \rightarrow B2_7 \rightarrow$ $C1_1 \rightarrow C1_4 \rightarrow C1_5 \rightarrow C1_8$
	$C1_1 \rightarrow C1_4 \rightarrow$ $C1_5 \rightarrow C1_8$	$C1_2 \rightarrow C2_2$ $C1_3 \rightarrow C2_3$ $C1_6 \rightarrow C2_6$ $C1_7 \rightarrow C2_7$	$C2_1 \rightarrow C2_4 \rightarrow$ $C2_5 \rightarrow C2_8$	$C2_1 \rightarrow C2_4 \rightarrow C2_5 \rightarrow C2_8 \rightarrow$ $A1_1 \rightarrow A1_4 \rightarrow A1_5 \rightarrow A1_8$

TABLE 7-27

Connection Table for 192 Slots, 10 Poles, spp=6 2/5; (y=38; y_b=19; y_f=19; a=-2; d=odd; P=even)

REFERENCE WORKING DIAGRAM Fig. 7-27

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
4	16	↑	$A1_1$ = 1	$A1_2$ = 180	↓	↑	$B1_1$ = 33	$B1_2$ = 20	↓	↑	$C1_1$ = 65	$C1_2$ = 52	↓
	16	↑	$A2_1$ = 78	$A2_2$ = 65	↓	↓	$B2_1$ = 14	$B2_2$ = 1	↑	↓	$C2_1$ = 46	$C2_2$ = 46	↑
	16	↓	$A1_3$ = 97	$A1_4$ = 84	↑	↓	$B1_3$ = 129	$B1_4$ = 116	↑	↓	$C1_3$ = 161	$C1_4$ = 148	↑
	16	↓	$A2_3$ = 174	$A2_4$ = 161	↑	↑	$B2_3$ = 110	$B2_4$ = 97	↓	↑	$C2_3$ = 142	$C2_4$ = 129	↓

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_4$ $A2_1 \rightarrow A2_3$ $A1_4 \rightarrow A2_2$	$A1_3$	$A1_3 \rightarrow B1_3$
	$B1_3$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B2_3$ $B1_4 \rightarrow B2_4$	$B1_1$	$B1_1 \rightarrow C1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C2_3$ $C1_4 \rightarrow C2_4$	$C1_3$	$C1_3 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_4$	$A1_2 \rightarrow A2_4$ $A1_3 \rightarrow A2_1$	$A2_2 \rightarrow A2_3$	$A2_2 \rightarrow A2_3 \rightarrow B1_2 \rightarrow B1_3$
	$B1_2 \rightarrow B1_3$	$B1_4 \rightarrow B2_4$ $B1_1 \rightarrow B2_1$	$B2_2 \rightarrow B2_3$	$B2_2 \rightarrow B2_3 \rightarrow C1_1 \rightarrow C1_4$
	$C1_1 \rightarrow C1_4$	$C1_2 \rightarrow C2_2$ $C1_3 \rightarrow C2_3$	$C2_1 \rightarrow C2_4$	$C2_1 \rightarrow C2_4 \rightarrow A1_1 \rightarrow A1_4$

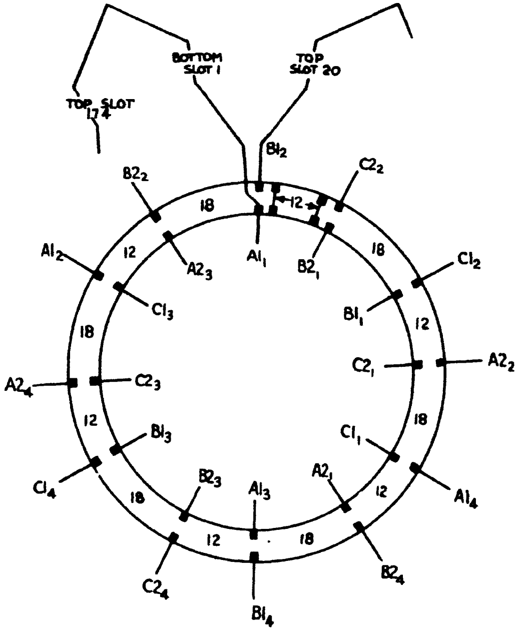


Fig. 7-27. Working Diagram for 192 slots, 10 poles, spp = 6 2/5

TABLE 7-28

Connection Table for 168 Slots, 10 Poles, spp=5 3/5;($y=34$; $y_b=17$; $y_f=17$; $a=+2$; d=odd; P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-28

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	14	↑	$A1_1$ = 1	$A1_2$ = 124	↓	↑	$B1_1$ = 29	$B1_2$ = 152	↓	↑	$C1_1$ = 57	$C1_2$ = 12	↓
	14	↓	$A2_1$ = 18	$A2_2$ = 141	↑	↓	$B2_1$ = 46	$B2_2$ = 1	↑	↓	$C2_1$ = 74	$C2_2$ = 29	↑
	14	↓	$A1_3$ = 85	$A1_4$ = 40	↑	↓	$B1_3$ = 113	$B1_4$ = 68	↑	↓	$C1_3$ = 141	$C1_4$ = 96	↑
	14	↑	$A2_3$ = 102	$A2_4$ = 57	↓	↑	$B2_3$ = 130	$B2_4$ = 85	↓	↑	$C2_3$ = 158	$C2_4$ = 113	↓

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A2_3$ $A1_4 \rightarrow A2_4$	$A1_3$	$A1_3 \rightarrow B1_3$
	$B1_3$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B2_3$ $B1_4 \rightarrow B2_4$	$B1_1$	$B1_1 \rightarrow C1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C2_3$ $C1_4 \rightarrow C2_4$	$C1_3$	$C1_3 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_4$	$A1_2 \rightarrow A2_2$ $A1_3 \rightarrow A2_3$	$A2_1 \rightarrow A2_4$	$A2_1 \rightarrow A2_4 \rightarrow B1_2 \rightarrow B1_3$
	$B1_2 \rightarrow B1_3$	$B1_1 \rightarrow B2_1$ $B1_4 \rightarrow B2_4$	$B2_2 \rightarrow B2_3$	$B2_2 \rightarrow B2_3 \rightarrow C1_1 \rightarrow C1_4$
	$C1_1 \rightarrow C1_4$	$C1_2 \rightarrow C2_2$ $C1_3 \rightarrow C2_3$	$C2_1 \rightarrow C2_4$	$C2_1 \rightarrow C2_4 \rightarrow A1_1 \rightarrow A1_4$

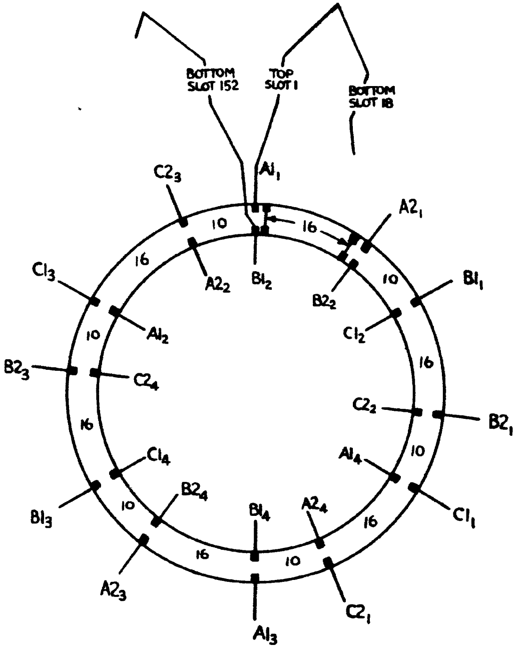


Fig. 7-28. Working Diagram for 168 slots, 10 poles, spp = 5 3/5

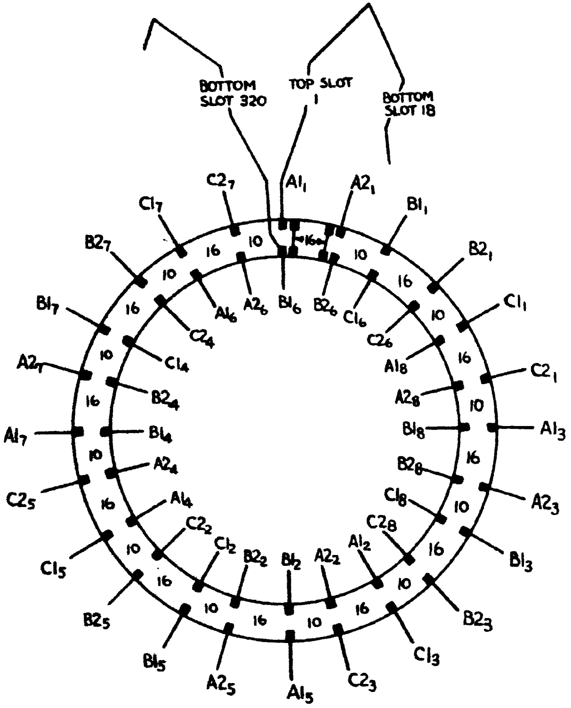


Fig. 7-29. Working Diagram for 336 slots, 20 poles, spp = 5 3/5

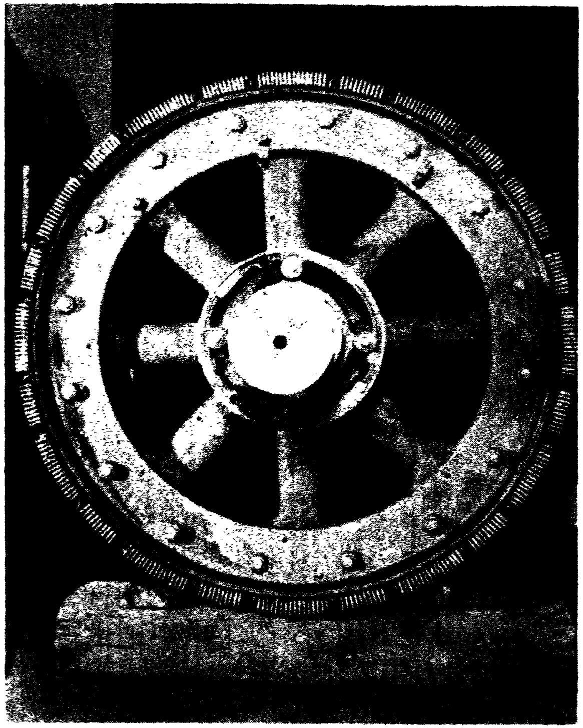


Fig. 7-29a. Photograph of the connection end of the winding shown by Working Diagram Fig. 7-29. The photograph shows the beginnings and ends of the winding parts before connection to a single delta.

TABLE 7-29

Connection Table for 336 Slots, 20 Poles, spp=5 3/5; ($y=34$; $y_b=17$; $y_f=17$; $a=+2$; $d=\text{odd}$; $P=\text{odd}$)

REFERENCE WORKING DIAGRAM 7-29

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
8	14	↑	$A1_1$ = 1	$A1_2$ = 124	↓	↑	$B1_1$ = 29	$B1_2$ = 152	↓	↑	$C1_1$ = 57	$C1_2$ = 180	↓
	14	↓	$A2_1$ = 18	$A2_2$ = 141	↑	↓	$B2_1$ = 46	$B2_2$ = 169	↑	↓	$C2_1$ = 74	$C2_2$ = 197	↑
	14	↓	$A1_3$ = 85	$A1_4$ = 208	↑	↓	$B1_3$ = 113	$B1_4$ = 236	↑	↓	$C1_3$ = 141	$C1_4$ = 264	↑
	14	↑	$A2_3$ = 102	$A2_4$ = 225	↓	↑	$B2_3$ = 130	$B2_4$ = 253	↓	↑	$C2_3$ = 158	$C2_4$ = 281	↓
	14	↑	$A1_5$ = 169	$A1_6$ = 292	↓	↑	$B1_5$ = 197	$B1_6$ = 320	↓	↑	$C1_5$ = 225	$C1_6$ = 12	↓
	14	↓	$A2_5$ = 186	$A2_6$ = 309	↑	↓	$B2_5$ = 214	$B2_6$ = 1	↑	↓	$C2_5$ = 242	$C2_6$ = 29	↑
	14	↓	$A1_7$ = 253	$A1_8$ = 40	↑	↓	$B1_7$ = 281	$B1_8$ = 68	↑	↓	$C1_7$ = 309	$C1_8$ = 96	↑
	14	↑	$A2_7$ = 270	$A2_8$ = 57	↓	↑	$B2_7$ = 298	$B2_8$ = 85	↓	↑	$C2_7$ = 326	$C2_8$ = 113	↓

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \to A2_2$ $A2_1 \to A2_3$ $A2_4 \to A1_4$ $A1_3 \to A1_5$ $A1_6 \to A2_6$ $A2_5 \to A2_7$ $A2_8 \to A1_8$	$A1_7$	$A1_7 \to B1_3$
	$B1_3$	$B1_2 \to B2_2$ $B2_1 \to B2_7$ $B2_4 \to B1_4$ $B1_7 \to B1_5$ $B1_6 \to B2_6$ $B2_5 \to B2_3$ $B2_8 \to B1_8$	$B1_1$	$B1_1 \to C1_5$
	$C1_5$	$C1_2 \to C2_2$ $C2_1 \to C2_3$ $C2_4 \to C1_4$ $C1_7 \to C1_1$ $C1_6 \to C2_6$ $C2_5 \to C2_7$ $C2_8 \to C1_8$	$C1_3$	$C1_3 \to A1_1$
2	$A1_1 \to A1_5$	$A1_2 \to A2_2$ $A2_1 \to A2_3$ $A2_4 \to A1_4$ $A1_6 \to A2_6$ $A2_5 \to A2_7$ $A2_8 \to A1_8$	$A1_3 \to A1_7$	$A1_3 \to A1_7 \to B1_3 \to B1_7$
	$B1_3 \to B1_7$	$B1_2 \to B2_2$ $B2_1 \to B2_7$ $B2_4 \to B1_4$ $B1_6 \to B2_6$ $B2_5 \to B2_3$ $B2_8 \to B1_8$	$B1_1 \to B1_5$	$B1_1 \to B1_5 \to C1_1 \to C1_5$
	$C1_1 \to C1_5$	$C1_2 \to C2_2$ $C2_1 \to C2_3$ $C2_4 \to C1_4$ $C1_6 \to C2_6$ $C2_5 \to C2_7$ $C2_8 \to C1_8$	$C1_3 \to C1_7$	$C1_3 \to C1_7 \to A1_1 \to A1_5$
4	$A1_1 \to A1_4 \to$ $A1_5 \to A1_8$	$A1_2 \to A2_2$ $A1_3 \to A2_3$ $A1_6 \to A2_6$ $A1_7 \to A2_7$	$A2_1 \to A2_4 \to$ $A2_5 \to A2_8$	$A2_1 \to A2_4 \to A2_5 \to A2_8 \to$ $B1_2 \to B1_3 \to B1_6 \to B1_7$
	$B1_2 \to B1_3 \to$ $B1_6 \to B1_7$	$B1_1 \to B2_1$ $B1_4 \to B2_4$ $B1_5 \to B2_5$ $B1_8 \to B2_8$	$B2_2 \to B2_3 \to$ $B2_6 \to B2_7$	$B2_2 \to B2_3 \to B2_6 \to B2_7 \to$ $C1_1 \to C1_4 \to C1_5 \to C1_8$
	$C1_1 \to C1_4 \to$ $C1_5 \to C1_8$	$C1_2 \to C2_2$ $C1_3 \to C2_3$ $C1_6 \to C2_6$ $C1_7 \to C2_7$	$C2_1 \to C2_4 \to$ $C2_5 \to C2_8$	$C2_1 \to C2_4 \to C2_5 \to C2_8 \to$ $A1_1 \to A1_4 \to A1_5 \to A1_8$

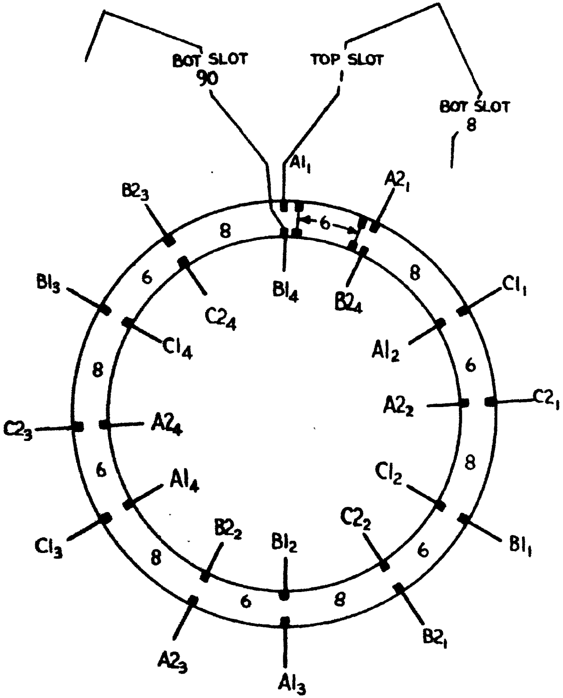


Fig. 7-30. Working Diagram for 96 slots, 14 poles, spp = 2 2/7

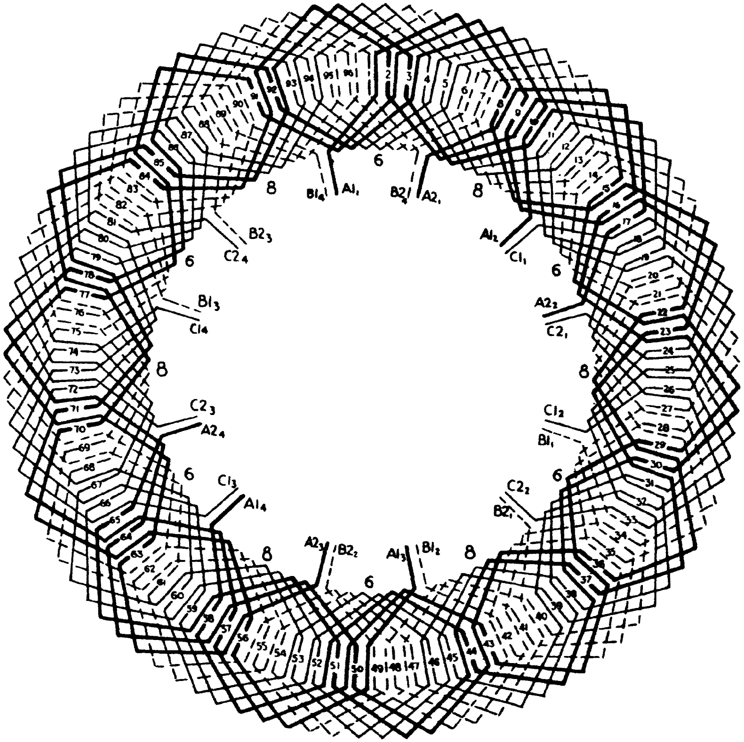


Fig. 7-30a. Fully developed diagram for 96 slots, 14 poles, spp = 2 2/7

TABLE 7-30

Connection Table for 96 Slots, 14 Poles, spp=2 2/7; ($y=14$; $y_b=7$; $y_f=7$; $a=+2$; d=odd; P=odd)

REFERENCE WORKING DIAGRAM 7-30

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	8	↑	$A1_1 = 1$	$A1_2 = 10$	↓	↑	$B1_1 = 33$	$B1_2 = 42$	↓	↑	$C1_1 = 17$	$C1_2 = 26$	↓
	8	↓	$A2_1 = 8$	$A2_2 = 17$	↑	↓	$B2_1 = 40$	$B2_2 = 49$	↑	↓	$C2_1 = 24$	$C2_2 = 33$	↑
	8	↓	$A1_3 = 49$	$A1_4 = 58$	↑	↓	$B1_3 = 81$	$B1_4 = 90$	↑	↓	$C1_3 = 65$	$C1_4 = 74$	↑
	8	↑	$A2_3 = 56$	$A2_4 = 65$	↓	↑	$B2_3 = 88$	$B2_4 = 1$	↓	↑	$C2_3 = 72$	$C2_4 = 81$	↓

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A1_4 \rightarrow A2_4$ $A2_1 \rightarrow A2_3$	$A1_3$	$A1_3 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B1_4 \rightarrow B2_4$ $B2_1 \rightarrow B2_3$	$B1_3$	$B1_3 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_2$ $C1_4 \rightarrow C2_4$ $C2_1 \rightarrow C2_3$	$C1_1$	$C1_1 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_4$	$A1_2 \rightarrow A2_2$ $A1_3 \rightarrow A2_3$	$A2_1 \rightarrow A2_4$	$A2_1 \rightarrow A2_4 \rightarrow B1_1 \rightarrow B1_4$
	$B1_1 \rightarrow B1_4$	$B1_2 \rightarrow B2_2$ $B1_3 \rightarrow B2_3$	$B2_1 \rightarrow B2_4$	$B2_1 \rightarrow B2_4 \rightarrow C1_2 \rightarrow C1_3$
	$C1_2 \rightarrow C1_3$	$C1_1 \rightarrow C2_1$ $C1_4 \rightarrow C2_4$	$C2_3 \rightarrow C2_2$	$C2_3 \rightarrow C2_2 \rightarrow A1_1 \rightarrow A1_4$

TABLE 7-31

Connection Table for 192 Slots, 28 Poles, spp=2 2/7; (y=14; y_b=7; y_f=7; a=+2; d=odd, P=odd)

REFERENCE WORKING DIAGRAM 7-31

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
8	8	↑	$A1_1$ = 1	$A1_2$ = 106	↓	↑	$B1_1$ = 33	$B1_2$ = 138	↓	↑	$C1_1$ = 17	$C1_2$ = 122	↓
	8	↓	$A2_1$ = 8	$A2_2$ = 113	↑	↓	$B2_1$ = 40	$B2_2$ = 145	↑	↓	$C2_1$ = 24	$C2_2$ = 129	↑
	8	↓	$A1_3$ = 49	$A1_4$ = 154	↑	↓	$B1_3$ = 81	$B1_4$ = 186	↑	↓	$C1_3$ = 65	$C1_4$ = 170	↑
	8	↑	$A2_3$ = 56	$A2_4$ = 161	↓	↑	$B2_3$ = 88	$B2_4$ = 1	↓	↑	$C2_3$ = 72	$C2_4$ = 177	↓
	8	↑	$A1_5$ = 97	$A1_6$ = 10	↓	↑	$B1_5$ = 129	$B1_6$ = 42	↓	↑	$C1_5$ = 113	$C1_6$ = 26	↓
	8	↓	$A2_5$ = 104	$A2_6$ = 17	↑	↓	$B2_5$ = 136	$B2_6$ = 49	↑	↓	$C2_5$ = 120	$C2_6$ = 33	↑
	8	↓	$A1_7$ = 145	$A1_8$ = 58	↑	↓	$B1_7$ = 177	$B1_8$ = 90	↑	↓	$C1_7$ = 161	$C1_8$ = 74	↑
	8	↑	$A2_7$ = 152	$A2_8$ = 65	↓	↑	$B2_7$ = 184	$B2_8$ = 97	↓	↑	$C2_7$ = 168	$C2_8$ = 81	↓

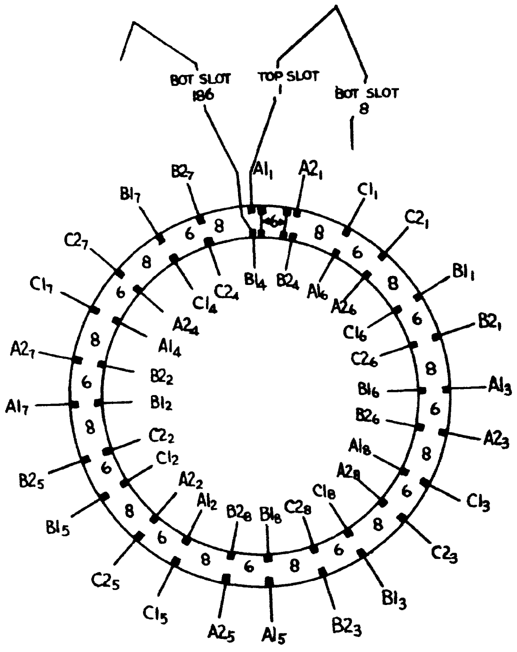


Fig. 7-31. Working diagram for 192 slots, 28 poles, spp = 2 2/7

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A2_3$ $A2_4 \rightarrow A1_4$ $A1_3 \rightarrow A1_5$ $A1_6 \rightarrow A2_6$ $A2_5 \rightarrow A2_7$ $A2_8 \rightarrow A1_8$	$A1_7$	$A1_7 \rightarrow B1_5$
	$B1_5$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$ $B1_1 \rightarrow B1_7$ $B1_6 \rightarrow B2_6$ $B2_5 \rightarrow B2_7$ $B2_8 \rightarrow B1_8$	$B1_3$	$B1_3 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C2_7$ $C2_4 \rightarrow C1_4$ $C1_5 \rightarrow C1_7$ $C1_6 \rightarrow C2_6$ $C2_5 \rightarrow C2_3$ $C2_8 \rightarrow C1_8$	$C1_1$	$C1_1 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_5$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A2_3$ $A2_4 \rightarrow A1_4$ $A1_6 \rightarrow A2_6$ $A2_5 \rightarrow A2_7$ $A2_8 \rightarrow A1_8$	$A1_3 \rightarrow A1_7$	$A1_3 \rightarrow A1_7 \rightarrow B1_1 \rightarrow B1_5$
	$B1_1 \rightarrow B1_5$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$ $B1_6 \rightarrow B2_6$ $B2_5 \rightarrow B2_7$ $B2_8 \rightarrow B1_8$	$B1_3 \rightarrow B1_7$	$B1_3 \rightarrow B1_7 \rightarrow C1_3 \rightarrow C1_7$
	$C1_3 \rightarrow C1_7$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C2_7$ $C2_4 \rightarrow C1_4$ $C1_6 \rightarrow C2_6$ $C2_5 \rightarrow C2_3$ $C2_8 \rightarrow C1_8$	$C1_1 \rightarrow C1_5$	$C1_1 \rightarrow C1_5 \rightarrow A1_1 \rightarrow A1_5$
4	$A1_1 \rightarrow A1_4 \rightarrow$ $A1_5 \rightarrow A1_8$	$A1_2 \rightarrow A2_2$ $A1_3 \rightarrow A2_3$ $A1_6 \rightarrow A2_6$ $A1_7 \rightarrow A2_7$	$A2_1 \rightarrow A2_4 \rightarrow$ $A2_5 \rightarrow A2_8$	$A2_1 \rightarrow A2_4 \rightarrow A2_5 \rightarrow A2_8 \rightarrow$ $B1_1 \rightarrow B1_4 \rightarrow B1_5 \rightarrow B1_8$
	$B1_1 \rightarrow B1_4 \rightarrow$ $B1_5 \rightarrow B1_8$	$B1_2 \rightarrow B2_2$ $B1_3 \rightarrow B2_3$ $B1_6 \rightarrow B2_6$ $B1_7 \rightarrow B2_7$	$B2_1 \rightarrow B2_4 \rightarrow$ $B2_5 \rightarrow B2_8$	$B2_1 \rightarrow B2_4 \rightarrow B2_5 \rightarrow B2_8 \rightarrow$ $C1_2 \rightarrow C1_3 \rightarrow C1_6 \rightarrow C1_7$
	$C1_2 \rightarrow C1_3 \rightarrow$ $C1_6 \rightarrow C1_7$	$C1_1 \rightarrow C2_1$ $C1_4 \rightarrow C2_4$ $C1_5 \rightarrow C2_5$ $C1_8 \rightarrow C2_8$	$C2_2 \rightarrow C2_3 \rightarrow$ $C2_6 \rightarrow C2_7$	$C2_2 \rightarrow C2_3 \rightarrow C2_6 \rightarrow C2_7 \rightarrow$ $A1_1 \rightarrow A1_4 \rightarrow A1_5 \rightarrow A1_8$

TABLE 7-32

Connection Table for 180 Slots, 14 Poles, spp=4 2/7; $\left(y=26;\ y_b=13;\ y_f=13;\ a=+2;\ d=\text{odd};\ P=\text{odd}\right)$

REFERENCE WORKING DIAGRAM Fig. 7-32

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	15	↑	$A1_1$ = 1	$A1_2$ = 18	↓	↑	$B1_1$ = 61	$B1_2$ = 78	↓	↑	$C1_1$ = 31	$C1_2$ = 48	↓
	15	↓	$A2_1$ = 14	$A2_2$ = 31	↑	↓	$B2_1$ = 74	$B2_2$ = 91	↑	↓	$C2_1$ = 44	$C2_2$ = 61	↑
	15	↓	$A1_3$ = 91	$A1_4$ = 108	↑	↓	$B1_3$ = 151	$B1_4$ = 168	↑	↓	$C1_3$ = 121	$C1_4$ = 138	↑
	15	↑	$A2_3$ = 104	$A2_4$ = 121	↓	↑	$B2_3$ = 164	$B2_4$ = 1	↓	↑	$C2_3$ = 134	$C2_4$ = 151	↓

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A2_3$ $A1_4 \rightarrow A2_4$	$A1_3$	$A1_3 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B2_3$ $B1_4 \rightarrow B2_4$	$B1_3$	$B1_3 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C2_3$ $C1_4 \rightarrow C2_4$	$C1_1$	$C1_1 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_4$	$A1_2 \rightarrow A2_2$ $A1_3 \rightarrow A2_3$	$A2_1 \rightarrow A2_4$	$A2_1 \rightarrow A2_4 \rightarrow B1_1 \rightarrow B1_4$
	$B1_1 \rightarrow B1_4$	$B1_2 \rightarrow B2_2$ $B1_3 \rightarrow B2_3$	$B2_1 \rightarrow B2_4$	$B2_1 \rightarrow B2_4 \rightarrow C1_2 \rightarrow C1_3$
	$C1_2 \rightarrow C1_3$	$C1_2 \rightarrow C2_2$ $C1_4 \rightarrow C2_4$	$C2_2 \rightarrow C2_3$	$C2_2 \rightarrow C2_3 \rightarrow A1_1 \rightarrow A1_4$

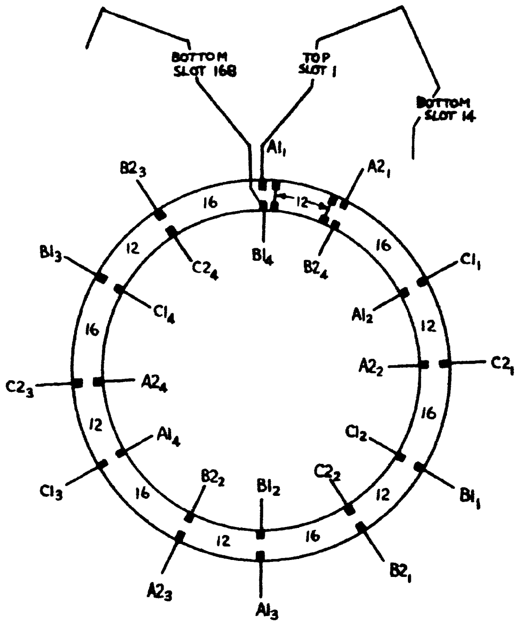


Fig. 7-32. Working diagram for 180 slots, 14 poles, spp = 4 2/7

TABLE 7-33

Connection Table for 57 Slots, 8 Poles, spp=2 3/8; $(y=14;\ y_b=7;\ y_f=7;\ a=-2;\ d=\text{even};\ P=\text{odd})$

REFERENCE WORKING DIAGRAM Fig. 7-33

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	10	↑	$A1_1$ = 1	$A1_2$ = 39	↓	↑	$B1_1$ = 20	$B1_2$ = 1	↓	↑	$C1_1$ = 39	$C1_2$ = 20	↓
	9	↓	$A2_1$ = 51	$A2_2$ = 46	↑	↓	$B2_1$ = 13	$B2_2$ = 8	↑	↓	$C2_1$ = 32	$C2_2$ = 27	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow C1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$	$B2_1$	$B2_1 \rightarrow A1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$	$C2_1$	$C2_1 \rightarrow B1_1$

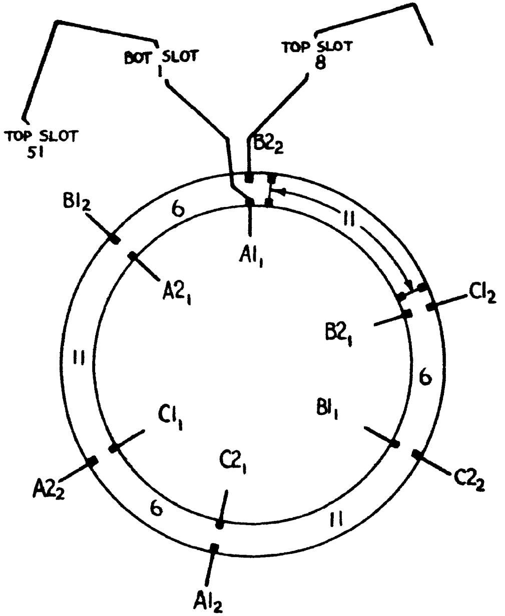


Fig. 7-33. Working diagram for 57 slots, 8 poles, spp = 2 3/8

TABLE 7-34

Connection Table for 114 Slots, 16 Poles, spp=2 3/8;$\left(y=14;\ y_b=7;\ y_f=7;\ a=-2;\ d=\text{even};\ P=\text{odd}\right)$

REFERENCE WORKING DIAGRAM Fig. 7-34

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
4	10	↑	$A1_1$ = 1	$A1_2$ = 96	↓	↑	$B1_1$ = 20	$B1_2$ = 1	↓	↑	$C1_1$ = 39	$C1_2$ = 20	↓
	9	↓	$A2_1$ = 51	$A2_2$ = 46	↑	↓	$B2_1$ = 13	$B2_2$ = 8	↑	↓	$C2_1$ = 32	$C2_2$ = 27	↑
	10	↑	$A1_3$ = 58	$A1_4$ = 39	↓	↑	$B1_3$ = 77	$B1_4$ = 58	↓	↑	$C1_3$ = 96	$C1_4$ = 77	↓
	9	↓	$A2_3$ = 108	$A2_4$ = 103	↑	↓	$B2_3$ = 70	$B2_4$ = 65	↑	↓	$C2_3$ = 89	$C2_4$ = 84	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_4$ $A1_3 \rightarrow A2_3$ $A1_4 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow C1_1$
	$B1_3$	$B1_2 \rightarrow B2_2$ $B1_1 \rightarrow B2_3$ $B1_4 \rightarrow B2_4$	$B2_1$	$B2_1 \rightarrow A1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$ $C1_3 \rightarrow C2_1$ $C1_4 \rightarrow C2_4$	$C2_3$	$C2_3 \rightarrow B1_3$
2	$A1_1 \rightarrow A1_3$	$A1_2 \rightarrow A2_4$ $A1_4 \rightarrow A2_2$	$A2_1 \rightarrow A2_3$	$A2_1 \rightarrow A3_3 \rightarrow C1_1 \rightarrow C1_3$
	$B1_1 \rightarrow B1_3$	$B1_2 \rightarrow B2_2$ $B1_4 \rightarrow B2_4$	$B2_1 \rightarrow B2_3$	$B2_1 \rightarrow B2_3 \rightarrow A1_1 \rightarrow A1_3$
	$C1_1 \rightarrow C1_3$	$C1_2 \rightarrow C2_2$ $C1_4 \rightarrow C2_4$	$C2_1 \rightarrow C2_3$	$C2_1 \rightarrow C2_3 \rightarrow B1_1 \rightarrow B1_3$

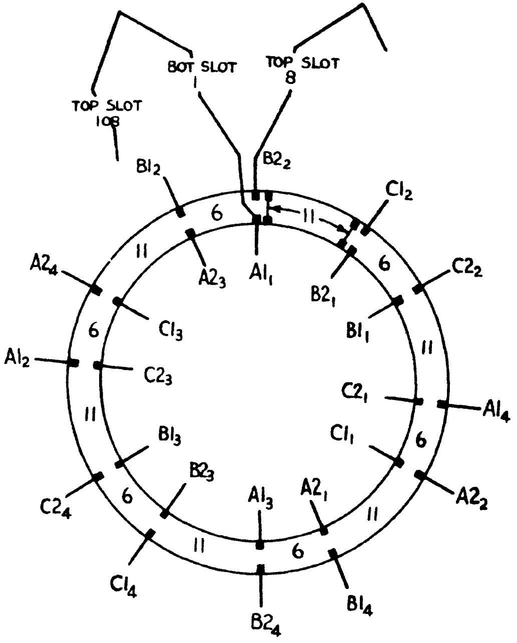


Fig. 7-34. Working diagram for 114 slots, 16 poles, spp = 2 3/8

TABLE 7-35

Connection Table for 171 Slots, 24 Poles, spp=2 3/8; $(y=14;\ y_b=7;\ y_f=7;\ a=-2;\ d=\text{even};\ P=\text{odd})$

REFERENCE WORKING DIAGRAM Fig. 7-35

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
6	10	↑	$A1_1$ = 1	$A1_2$ = 39	↓	↑	$B1_1$ = 20	$B1_2$ = 58	↓	↑	$C1_1$ = 39	$C1_2$ = 77	↓
	9	↓	$A2_1$ = 51	$A2_2$ = 103	↑	↓	$B2_1$ = 13	$B2_2$ = 65	↑	↓	$C2_1$ = 32	$C2_2$ = 84	↑
	10	↑	$A1_3$ = 58	$A1_4$ = 96	↓	↑	$B1_3$ = 77	$B1_4$ = 115	↓	↑	$C1_3$ = 96	$C1_4$ = 134	↓
	9	↓	$A2_3$ = 108	$A2_4$ = 160	↑	↓	$B2_3$ = 70	$B2_4$ = 122	↑	↓	$C2_3$ = 89	$C2_4$ = 141	↑
	10	↑	$A1_5$ = 115	$A1_6$ = 153	↓	↑	$B1_5$ = 134	$B1_6$ = 1	↓	↑	$C1_5$ = 153	$C1_6$ = 20	↓
	9	↓	$A2_5$ = 165	$A2_6$ = 46	↑	↓	$B2_5$ = 127	$B2_6$ = 8	↑	↓	$C2_5$ = 146	$C2_6$ = 27	↑

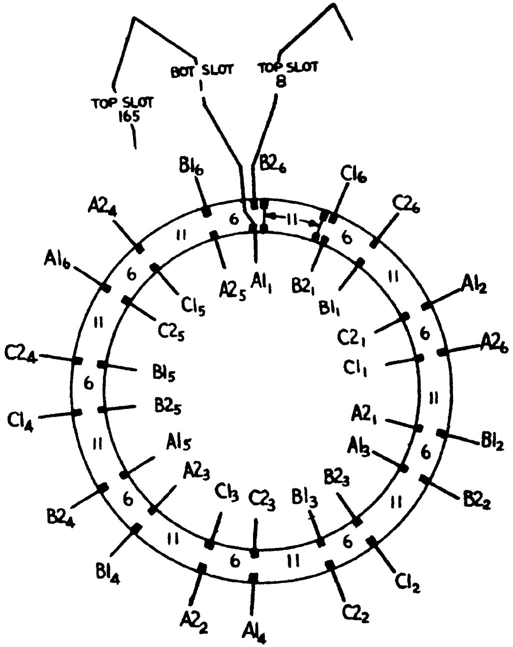


Fig. 7-35. Working diagram for 171 slots, 24 poles, spp = 2 3/8

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_6$ $A2_2 \rightarrow A1_4$ $A1_6 \rightarrow A2_4$ $A2_5 \rightarrow A1_5$ $A2_3 \rightarrow A1_3$	$A2_1$	$A2_1 \rightarrow B1_1$
	$B1_3$	$B1_6 \rightarrow B2_6$ $B2_4 \rightarrow B1_4$ $B2_2 \rightarrow B1_2$ $B2_1 \rightarrow B1_5$ $B2_5 \rightarrow B1_3$	$B2_3$	$B2_3 \rightarrow C1_1$
	$C1_1$	$C1_6 \rightarrow C2_6$ $C1_2 \rightarrow C2_2$ $C2_4 \rightarrow C1_4$ $C2_1 \rightarrow C1_5$ $C2_5 \rightarrow C1_3$	$C2_3$	$C2_3 \rightarrow A1_1$
3	$A1_1 \rightarrow A1_3 \rightarrow A1_5$	$A1_2 \rightarrow A2_6$ $A2_2 \rightarrow A1_4$ $A1_6 \rightarrow A2_4$	$A2_1 \rightarrow A2_3 \rightarrow A2_5$	$A2_1 \rightarrow A2_3 \rightarrow A2_5 \rightarrow B1_1 \rightarrow B1_3 \rightarrow B1_5$
	$B1_1 \rightarrow B1_3 \rightarrow B1_5$	$B1_4 \rightarrow B2_4$ $B1_2 \rightarrow B2_2$ $B1_6 \rightarrow B2_6$	$B2_1 \rightarrow B2_3 \rightarrow B2_5$	$B2_1 \rightarrow B2_3 \rightarrow B2_5 \rightarrow C1_1 \rightarrow C1_3 \rightarrow C1_5$
	$C1_1 \rightarrow C1_3 \rightarrow C1_5$	$C1_4 \rightarrow C2_4$ $C1_2 \rightarrow C2_2$ $C1_6 \rightarrow C2_6$	$C2_1 \rightarrow C2_3 \rightarrow C2_5$	$C2_1 \rightarrow C2_3 \rightarrow C2_5 \rightarrow A1_1 \rightarrow A1_3 \rightarrow A1_5$

TABLE 7-36

Connection Table for 105 Slots, 8 Poles, spp=4 3/8; ($y=26$; $y_b=13$; $y_f=13$; $a=-2$; d=even; P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-36

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	18	↑	$A1_1 = 1$	$A1_2 = 71$	↓	↑	$B1_1 = 36$	$B1_2 = 1$	↓	↑	$C1_1 = 71$	$C1_2 = 36$	↓
	17	↓	$A2_1 = 93$	$A2_2 = 84$	↑	↓	$B2_1 = 23$	$B2_2 = 14$	↑	↓	$C2_1 = 58$	$C2_2 = 49$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$	$B2_1$	$B2_1 \rightarrow C1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$	$C2_1$	$C2_1 \rightarrow A1_1$

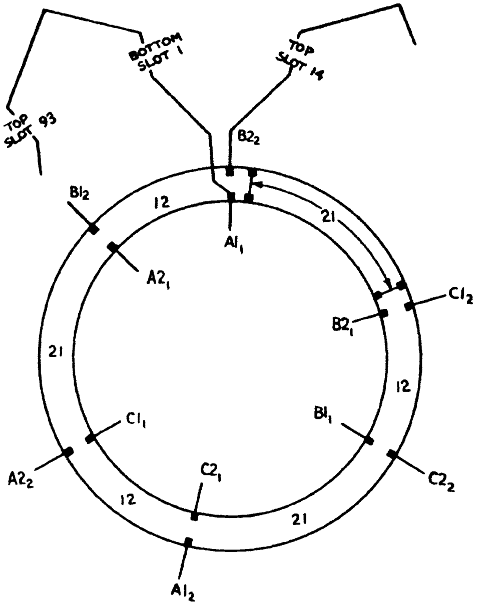


Fig. 7-36. Working Diagram for 105 slots, 8 poles, spp = 4 3/8

TABLE 7-37

Connection Table for 210 Slots, 16 Poles, spp=4 3/8; ($y=26$; $y_b=13$; $y_f=13$; $a=-2$; d=even; P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-37

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
4	18	↑	$A1_1$ = 1	$A1_2$ = 176	↓	↑	$B1_1$ = 36	$B1_2$ = 1	↓	↑	$C1_1$ = 71	$C1_2$ = 36	↓
	17	↓	$A2_1$ = 93	$A2_2$ = 84	↑	↓	$B2_1$ = 23	$B2_2$ = 14	↑	↓	$C2_1$ = 58	$C2_2$ = 49	↑
	18	↑	$A1_3$ = 106	$A1_4$ = 71	↓	↑	$B1_3$ = 141	$B1_4$ = 106	↓	↑	$C1_3$ = 176	$C1_4$ = 141	↓
	17	↓	$A2_3$ = 198	$A2_4$ = 189	↑	↓	$B2_3$ = 128	$B2_4$ = 119	↑	↓	$C2_3$ = 163	$C2_4$ = 154	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_4$ $A1_3 \rightarrow A2_3$ $A1_4 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow B1_3$
	$B1_3$	$B1_2 \rightarrow B2_2$ $B2_3 \rightarrow B1_1$ $B1_4 \rightarrow B2_4$	$B2_1$	$B2_1 \rightarrow C1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$ $C1_3 \rightarrow C2_1$ $C1_4 \rightarrow C2_4$	$C2_3$	$C2_3 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_3$	$A1_2 \rightarrow A2_4$ $A1_4 \rightarrow A2_2$	$A2_1 \rightarrow A2_3$	$A2_1 \rightarrow A2_3 \rightarrow B1_1 \rightarrow B1_3$
	$B1_1 \rightarrow B1_3$	$B1_2 \rightarrow B2_2$ $B1_4 \rightarrow B2_4$	$B2_1 \rightarrow B2_3$	$B2_1 \rightarrow B2_3 \rightarrow C1_1 \rightarrow C1_3$
	$C1_1 \rightarrow C1_3$	$C1_2 \rightarrow C2_2$ $C1_4 \rightarrow C2_4$	$C2_1 \rightarrow C2_3$	$C2_1 \rightarrow C2_3 \rightarrow A1_1 \rightarrow A1_3$

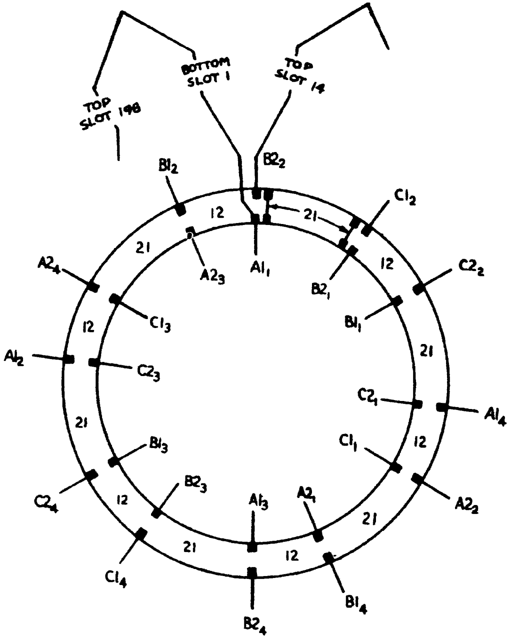


Fig. 7-37. Working Diagram for 210 slots, 16 poles, spp = 4 3/8

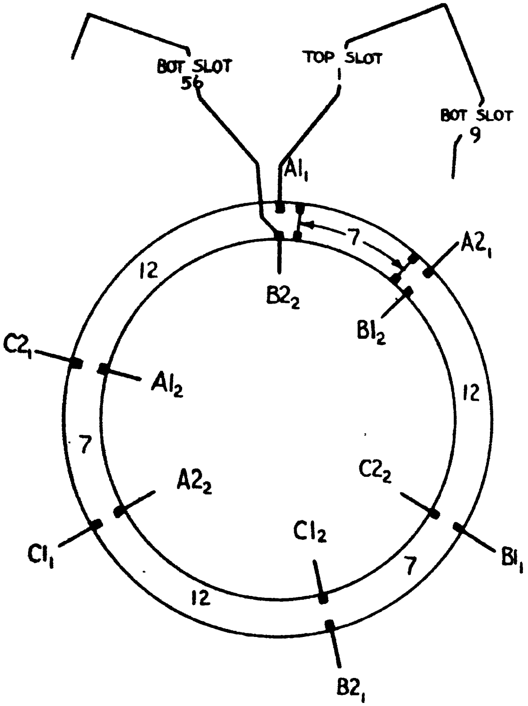


Fig. 7-38. Working diagram for 63 slots, 8 poles, spp = 2 5/8

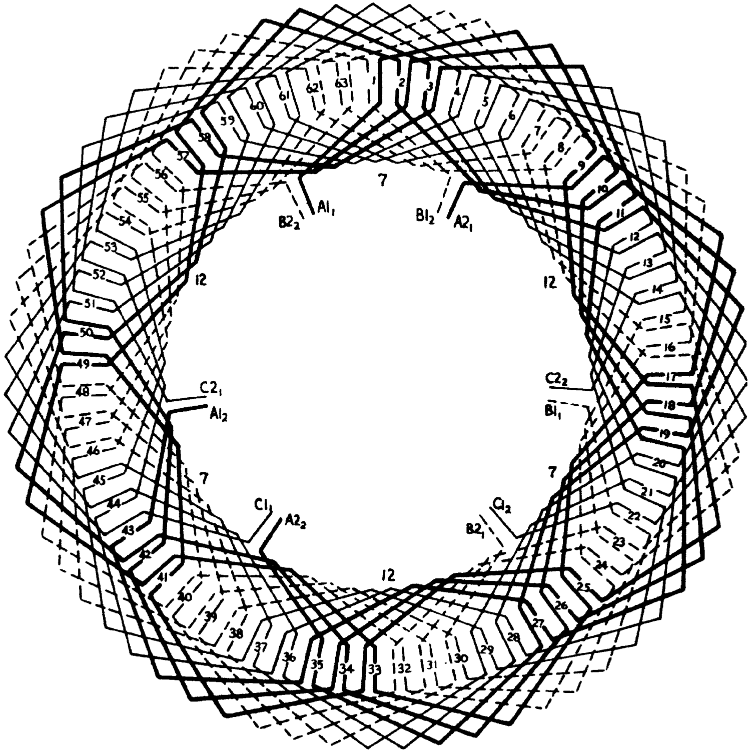


Fig. 7-38a. Fully developed diagram for 63 slots, 8 poles, spp = 2 5/8.

TABLE 7-38

Connection Table for 63 Slots, 8 Poles, spp=2 5/8; $(y=16;\ y_b=8;\ y_f=8;\ a=+2;\ d=\text{even};\ P=\text{odd})$

REFERENCE WORKING DIAGRAM Fig. 7-38

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	11	↑	$A1_1 = 1$	$A1_2 = 43$	↓	↑	$B1_1 = 22$	$B1_2 = 1$	↓	↑	$C1_1 = 43$	$C1_2 = 22$	↓
	10	↓	$A2_1 = 9$	$A2_2 = 35$	↑	↓	$B2_1 = 30$	$B2_2 = 56$	↑	↓	$C2_1 = 51$	$C2_2 = 14$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$	$B2_1$	$B2_1 \rightarrow C1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$	$C2_1$	$C2_1 \rightarrow A1_1$

TABLE 7-39

Connection Table for 126 Slots, 16 Poles, spp=2 5/8; (y=16; y_b=8; y_f=8; a=+2; d=even; P=odd)

REFERENCE WORKING DIAGRAM Fig. 7-39

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	11	↑	$A1_1$ = 1	$A1_2$ = 43	↓	↑	$B1_1$ = 22	$B1_2$ = 64	↓	↑	$C1_1$ = 43	$C1_2$ = 85	↓
	10	↓	$A2_1$ = 9	$A2_2$ = 35	↑	↓	$B2_1$ = 30	$B2_2$ = 56	↑	↓	$C2_1$ = 51	$C2_2$ = 77	↑
	11	↑	$A1_3$ = 64	$A1_4$ = 106	↓	↑	$B1_3$ = 85	$B1_4$ = 1	↓	↑	$C1_3$ = 106	$C1_4$ = 22	↓
	10	↓	$A2_3$ = 72	$A2_4$ = 98	↑	↓	$B2_3$ = 93	$B2_4$ = 119	↑	↓	$C2_3$ = 114	$C2_4$ = 14	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A1_3 \rightarrow A2_1$ $A1_4 \rightarrow A2_4$	$A2_3$	$A2_3 \rightarrow B1_3$
	$B1_3$	$B1_2 \rightarrow B2_2$ $B1_1 \rightarrow B2_3$ $B1_4 \rightarrow B2_4$	$B2_1$	$B2_1 \rightarrow C1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$ $C1_3 \rightarrow C2_1$ $C1_4 \rightarrow C2_4$	$C2_3$	$C2_3 \rightarrow A1_1$
2	$A1_1 \rightarrow A1_3$	$A1_2 \rightarrow A2_2$ $A1_4 \rightarrow A2_4$	$A2_1 \rightarrow A2_3$	$A2_1 \rightarrow A2_3 \rightarrow B1_1 \rightarrow B1_3$
	$B1_1 \rightarrow B1_3$	$B1_2 \rightarrow B2_2$ $B1_4 \rightarrow B2_4$	$B2_1 \rightarrow B2_3$	$B2_1 \rightarrow B2_3 \rightarrow C1_1 \rightarrow C1_3$
	$C1_1 \rightarrow C1_3$	$C1_2 \rightarrow C2_2$ $C1_4 \rightarrow C2_4$	$C2_1 \rightarrow C2_3$	$C2_1 \rightarrow C2_3 \rightarrow A1_1 \rightarrow A1_3$

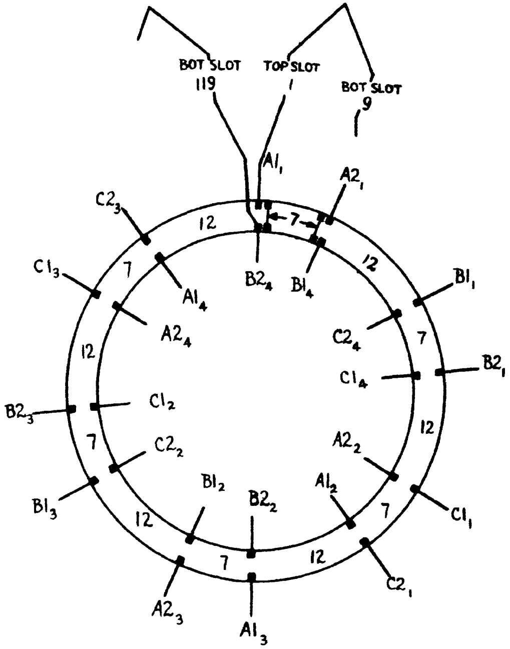


Fig. 7-39. Working Diagram for 126 Slots, 16 Poles, spp = 2 5/8

TABLE 7-40

Connection Table for 189 Slots, 24 Poles, spp=2 5/8; $\left(y=16;\ y_b=8;\ y_f=8;\ a=+2;\ d=\text{even};\ P=\text{odd}\right)$

REFERENCE WORKING DIAGRAM Fig. 7-40

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
6	11	↑	$A1_1$ = 1	$A1_2$ = 169	↓	↑	$B1_1$ = 22	$B1_2$ = 1	↓	↑	$C1_1$ = 43	$C1_2$ = 22	↓
	10	↓	$A2_1$ = 9	$A2_2$ = 161	↑	↓	$B2_1$ = 30	$B2_2$ = 182	↑	↓	$C2_1$ = 51	$C2_2$ = 14	↑
	11	↑	$A1_3$ = 64	$A1_4$ = 43	↓	↑	$B1_3$ = 85	$B1_4$ = 64	↓	↑	$C1_3$ = 106	$C1_4$ = 85	↓
	10	↓	$A2_3$ = 72	$A2_4$ = 35	↑	↓	$B2_3$ = 93	$B2_4$ = 56	↑	↓	$C2_3$ = 114	$C2_4$ = 77	↑
	11	↑	$A1_5$ = 127	$A1_6$ = 106	↓	↑	$B1_5$ = 148	$B1_6$ = 127	↓	↑	$C1_5$ = 169	$C1_6$ = 148	↓
	10	↓	$A2_5$ = 135	$A2_6$ = 98	↑	↓	$B2_5$ = 156	$B2_6$ = 119	↑	↓	$C2_5$ = 177	$C2_6$ = 140	↑

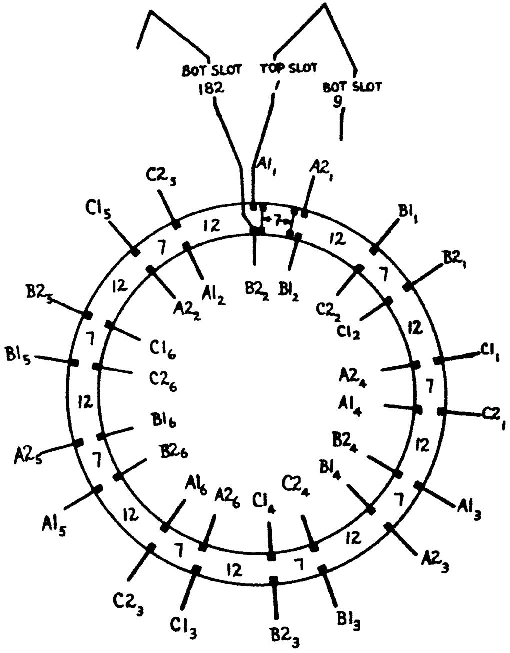


Fig. 7-40. Working Diagram for 189 slots, 24 poles, spp = 2 5/8

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A1_6 \rightarrow A2_6$ $A2_4 \rightarrow A1_4$ $A2_1 \rightarrow A1_3$ $A2_3 \rightarrow A1_5$	$A2_5$	$A2_5 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B1_6 \rightarrow B2_6$ $B2_4 \rightarrow B1_4$ $B2_1 \rightarrow B1_3$ $B2_3 \rightarrow B1_5$	$B2_5$	$B2_5 \rightarrow C1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$ $C1_6 \rightarrow C2_6$ $C2_4 \rightarrow C1_4$ $C2_1 \rightarrow C1_3$ $C2_3 \rightarrow C1_5$	$C2_5$	$C2_5 \rightarrow A1_1$
3	$A1_1 \rightarrow A1_3 \rightarrow A1_5$	$A1_2 \rightarrow A2_2$ $A1_4 \rightarrow A2_4$ $A1_6 \rightarrow A2_6$	$A2_1 \rightarrow A2_3 \rightarrow A2_5$	$A2_1 \rightarrow A2_3 \rightarrow A2_5 \rightarrow B1_1 \rightarrow B1_3 \rightarrow B1_5$
	$B1_1 \rightarrow B1_3 \rightarrow B1_5$	$B1_2 \rightarrow B2_2$ $B1_4 \rightarrow B2_4$ $B1_6 \rightarrow B2_6$	$B2_1 \rightarrow B2_3 \rightarrow B2_5$	$B2_1 \rightarrow B2_3 \rightarrow B2_5 \rightarrow C1_1 \rightarrow C1_3 \rightarrow C1_5$
	$C1_1 \rightarrow C1_3 \rightarrow C1_5$	$C1_2 \rightarrow C2_2$ $C1_4 \rightarrow C2_4$ $C1_6 \rightarrow C2_6$	$C2_1 \rightarrow C2_3 \rightarrow C2_5$	$C2_1 \rightarrow C2_3 \rightarrow C2_5 \rightarrow A1_1 \rightarrow A1_3 \rightarrow A1_5$

TABLE 7-41

Connection Table for 135 Slots, 8 Poles, spp=5 5/8; $(y=34;\ y_b=17;\ y_f=17;\ a=+2;\ d=\text{even};\ P=\text{odd})$

REFERENCE WORKING DIAGRAM Fig. 7-41

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	23	↑	$A1_1$ = 1	$A1_2$ = 91	↓	↑	$B1_1$ = 46	$B1_2$ = 1	↓	↑	$C1_1$ = 91	$C1_2$ = 46	↓
	22	↓	$A2_1$ = 18	$A2_2$ = 74	↑	↓	$B2_1$ = 63	$B2_2$ = 119	↑	↓	$C2_1$ = 108	$C2_2$ = 29	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$	$A2_1$	$A2_1 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$	$B2_1$	$B2_1 \rightarrow C1_1$
	$C1_1$	$C1_2 \rightarrow C2_2$	$C2_1$	$C2_1 \rightarrow A1_1$

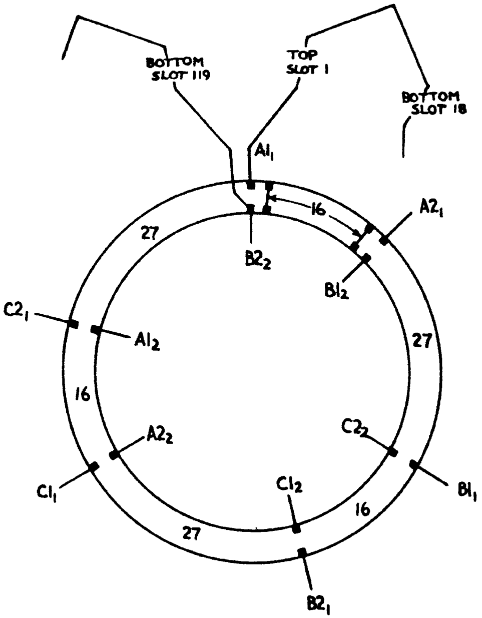


Fig. 7-41. Working Diagram for 135 slots, 8 poles, spp = 5 5/8

TABLE 7-42

Connection Table for 132 Slots, 26 Poles, spp=1 9/13; ($y=10$; $y_b=5$; $y_f=5$; $a=-2$; d=odd; P=even)

REFERENCE WORKING DIAGRAM Fig. 7-42

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
4	11	↑	$A1_1$ = 1	$A1_2$ = 28	↓	↑	$B1_1$ = 45	$B1_2$ = 72	↓	↑	$C1_1$ = 23	$C1_2$ = 50	↓
	11	↑	$A2_1$ = 62	$A2_2$ = 89	↓	↓	$B2_1$ = 40	$B2_2$ = 67	↑	↓	$C2_1$ = 18	$C2_2$ = 45	↑
	11	↓	$A1_3$ = 67	$A1_4$ = 94	↑	↓	$B1_3$ = 111	$B1_4$ = 6	↑	↓	$C1_3$ = 89	$C1_4$ = 116	↑
	11	↓	$A2_3$ = 128	$A2_4$ = 23	↑	↑	$B2_3$ = 106	$B2_4$ = 1	↓	↑	$C2_3$ = 84	$C2_4$ = 111	↓

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_4$ $A2_3 \rightarrow A2_1$ $A2_2 \rightarrow A1_4$	$A1_3$	$A1_3 \rightarrow C1_3$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$	$B1_3$	$B1_3 \rightarrow A1_1$
	$C1_3$	$C1_4 \rightarrow C2_4$ $C2_3 \rightarrow C2_1$ $C2_2 \rightarrow C1_2$	$C1_1$	$C1_1 \rightarrow B1_1$
2	$A1_1 \rightarrow A1_4$	$A1_2 \rightarrow A2_4$ $A1_3 \rightarrow A2_1$	$A2_2 \rightarrow A2_3$	$A2_2 \rightarrow A2_3 \rightarrow B1_1 \rightarrow B1_4$
	$B1_1 \rightarrow B1_4$	$B1_2 \rightarrow B2_2$ $B1_3 \rightarrow B2_3$	$B2_4 \rightarrow B2_1$	$B2_4 \rightarrow B2_1 \rightarrow C1_2 \rightarrow C1_3$
	$C1_2 \rightarrow C1_3$	$C1_1 \rightarrow C2_1$ $C1_4 \rightarrow C2_4$	$C2_2 \rightarrow C2_3$	$C2_2 \rightarrow C2_3 \rightarrow A1_1 \rightarrow A1_4$

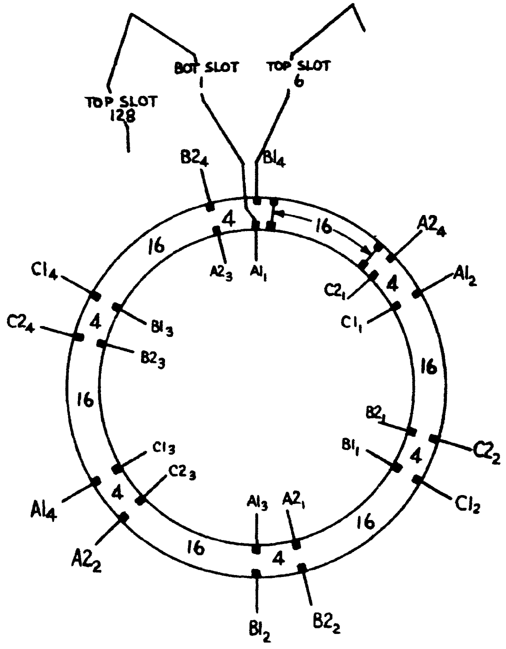


Fig. 7-42. Working Diagram for 132 slots, 26 poles, spp = 1 9/13

TABLE 7-43

Working Diagrams and Connection Tables are given for the following pole and slot numbers:

No. of Slots	No. of Poles									
	8	10	12	14	16	20	22	24	26	28
	Working Diagrams and Connection Tables									
54	7-17									
57	7-33									
63	7-38									
72		7-25								
81			7-18							
84		7-1								
90	7-22			7-6						
96		7-4		7-30						
105	7-36									
108					7-19					
114					7-34					
120				7-9			7-11			
126	7-20				7-39					
132									7-42	
135	7-41		7-23							
144		7-3				7-26	7-12		7-14	
150	7-21									
168		7-28				7-2			7-15	
171								7-35		
180				7-32	7-24					7-7
189								7-40		
192		7-27				7-5				7-31
210					7-37					
240				7-8			7-13			7-10
336						7-29			7-16	

For the corresponding values of spp, see Table 3-5.

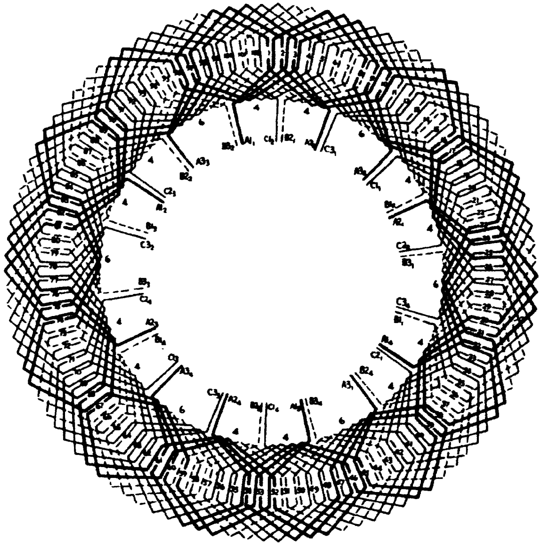


Fig. 7-43. Fully developed diagram for 102 slots, 14 poles, spp = 2 3/7.

TABLE 7-44

FOR THE DETERMINATION OF THE WINDING-PITCH AND THE NUMBER OF INTERLACED WINDINGS PER PHASE

Fraction of spp = $\frac{n}{d}$	1/4	3/4	1/5	2/5	3/5	4/5	1/7	2/7	3/7	4/7
$\frac{6n + a}{d}$	1	4	1	2	4	5	1	2	3	3
a	-2	-2	-1	-2	+2	+1	+1	+2	+3	-3

Fraction of spp = $\frac{n}{d}$	5/7	6/7	1/8	3/8	5/8	7/8	1/11	2/11	3/11	4/11
$\frac{6n + a}{d}$	4	5	1	2	4	5	1	1	2	2
a	-2	-1	+2	-2	+2	-2	+5	-1	+4	-2

Fraction of spp = $\frac{n}{d}$	5/11	6/11	7/11	8/11	9/11	10/11	1/13	2/13	3/13	4/13
$\frac{6n + a}{d}$	3	3	4	4	5	5	0	1	1	2
a	+3	-3	+2	-4	+1	-5	-6	+1	-5	+2

Fraction of spp = $\frac{n}{d}$	5/13	6/13	7/13	8/13	9/13	10/13	11/13	12/13	1/16	3/16
$\frac{6n + a}{d}$	2	3	3	4	4	5	5	6	0	1
a	-4	+3	-3	+4	-2	+5	-1	+6	-6	-2

Fraction of spp = $\frac{n}{d}$	5/16	7/16	9/16	11/16	13/16	15/16
$\frac{6n + a}{d}$	2	3	3	4	5	6
a	+2	+6	-6	-2	+2	+6

CHAPTER 8

UNBALANCED FRACTIONAL-SLOT WAVE WINDINGS

8-1. Features of the Windings Treated in This Chapter. The windings treated in this chapter have the same features as the unbalanced fractional-slot lap windings considered in Chapter 5, and all statements made in Art. 5-1 apply here also. Thus, 2 kinds of unbalanced windings are to be dealt with, one in which the number of slots and the denominator of the fraction of spp are both divisible by the number of phases (3) and the other in which the number of slots is not divisible by the number of phases. In the first case all slots have 2 coil sides; in the second case some coils are omitted and, therefore, some slots have only one coil side.

The corresponding values of number of slots, number of poles, and spp of the windings of the first kind are listed in the Master Table 3-5 and marked there by asterisks; the corresponding values of number of slots, number of poles and spp of the windings of the second kind are listed in Table 5-4.

As in previous chapters, left-hand coils are assumed. Furthermore, if there are more than 2 conductors per slot, i.e., more than one conductor per layer, the winding is considered as having a fictitious number of slots equal to the real number of slots times the number of conductors per layer. With this fictitious number of slots, the winding appears again as one which has only one conductor per layer, and the numbering of the slots coincides with the numbering of the conductors.

8-2. Connection Tables and How to Use Them. The Connection Tables given for various slots and pole combinations show:

(1) The position of the starts and ends of the winding parts of the 3 phases.
(2) The number of parts per phase.
(3) The number of coils per part.
(4) The polarity of the parts.
(5) The number and location of abnormal-front-pitch coils if there are any.

(6) The connections to be made for series or parallel, star or delta connection.

(7) Winding pitch = y.

(8) Front pitch = y_f.

(9) Back pitch = y_b.

There are too many unbalanced windings so that it is impractical to give Connection Tables for all of them. Tables 8-1 to 8-23 refer to pole and slot numbers which are more often encountered in practice. In Arts. 8-4 to 8-8, methods of laying out any kind of unbalanced windings are explained. The use of the Connection Tables will be explained by two examples.

Consider a 12-pole winding in 96 slots with 2 conductors per slot. The Master Table 3-5 shows that spp = 2 2/3. The Connection Table for this value of spp is Table 8-9. Each phase consists of 2 parts, and each part has the same number of coils. It shows that for 12 poles and 96 slots,the leads of phase A are the 2 upper conductors 1 and 9, and the 2 lower conductors 59 and 67 lying in slots 1, 9, 59, and 67; the leads of phase B lie at the top of slots 38 and 46 and at the bottom of slots 96 and 8; the leads of phase C lie at the top of slots 67 and 75 and at the bottom of slots 30 and 38. The back pitch of this winding is 8 slot pitches; the front pitch is also 8 slot pitches, i.e., upper conductor 1 is connected with lower conductor 1 + 8 = 9, and this latter conductor is connected with upper conductor 9 + 8 = 17, and so forth. The winding progresses clockwise.

Phases A and B each have 2 longer-front pitches in each part; phase C has 3 longer-front pitches in each part. The longer-front pitches lie before the upper conductors 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, and 16.

Series or two parallel circuits are possible. For series connection, A_2 must be connected with A_4, B_2 with B_4, and C_2 with C_4. For parallel connection, A_1 must be connected with A_4, A_3 with A_2, B_1 with B_4, B_3 with B_2, C_1 with C_4, and C_3 with C_2.

For star connection of the 3 phases, A_3 must be connected with B_3 and C_1 to the star point; for delta connection, A_3 must be connected with B_1, B_3 with C_3, and C_1 with A_1. This applies to series as well as to parallel connection of the 2 winding parts. In both cases, A_1, B_1, and C_3 are the leads to be conneced to slip rings or to the line.

As a second example, consider an 18-pole winding in 114 slots with 2 conductors per slot. The Master Table 3-5 yields for 18 poles and 114 slots spp = 2 1/9. The Connection Table for this value of spp is Table 8-20. It shows that each phase consists of 6 parts. The number of coils is not the same in all parts.

The first part of phase A, $A1_1$-$A1_2$, has 7 coils, the leads of which are upper conductor 1 and lower conductor 85, lying in the slots with the same numbers; the second and third parts of phase A, $A2_1$-$A2_2$ and $A3_1$-$A3_2$, have 6 coils each, the leads of which lie in upper conductor 20 and lower conductor 91 and in upper conductor 39 and lower conductor 110, respectively. The fourth part of phase A, $A1_3$-$A1_4$, has 7 coils with leads in upper conductor 58 and lower conductor 28. The fifth and sixth parts, $A2_3$-$A2_4$ and $A3_3$-$A3_4$, have 6 coils each, the same as parts 2 and 3, but with leads in upper conductor 77 and lower conductor 34 and upper conductor 96 and lower conductor 53, respectively.

Phase B has 7 coils in parts 3 and 6, i.e., in parts $B3_1$-$B3_2$ and $B3_3$-$B3_4$, and 6 coils in each of the other 4 parts; phase C has 7 coils in parts 2 and 5, i.e., in parts $C2_1$-$C2_2$ and $C2_3$-$C2_4$, and 6 coils in each of the other 4 parts.

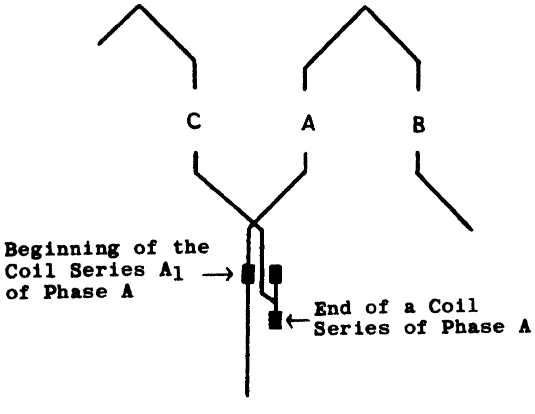
The back pitch of the winding is 6 slot pitches, the front pitch 7 slot pitches, i.e., upper conductor 1 is connected with lower conductor 1 + 6 = 7, and this conductor is connected with upper conductor 7 + 7 = 14, and so forth. The winding progresses clockwise. There are no abnormal-front pitches in this winding.

The first 3 parts and the second 3 parts of each phase must be connected in series, i.e., in phase A, $A1_2$ must be connected with $A2_2$, and $A2_1$ with $A3_1$; further $A1_4$ with $A2_4$, and $A2_3$ with $A3_3$. The free ends are $A1_1$ and $A3_2$ in the first 3 parts, and $A1_3$ and $A3_4$ in the second 3 parts. The connections to be made in phases B and C are obtained from those of phase A by substituting the symbols B and C, respectively, for A.

The 2 groups of each phase obtained in this manner can be connected in series as well as in parallel. For series connection, connect $A3_2$ with $A3_4$, $B3_2$ with $B3_4$, and $C3_2$ with $C3_4$. For parallel connection, connect $A1_1$ with $A3_4$, $A1_3$ with $A3_2$, $B1_1$ with $B3_4$, $B1_3$ with $B3_2$, $C1_1$ with $C3_4$, and $C1_3$ with $C3_2$.

For series star connection of the 3 phases, connect Al_3, Bl_3, and Cl_1 together; for series delta connection, connect Al_3 with Bl_1, Bl_3 with Cl_3, and Cl_1 with Al_1. This also applies to the parallel connection of the 2 parts. In both cases, Al_1, Bl_1, and Cl_3 are the leads to be connected to slip rings or to the line.

8-3. Working Diagrams. The Working Diagrams given in this chapter fall into 2 classes: those with the winding made up of coil series and abnormal-front pitches (d = 3 and d = 6), and those with no abnormal-front pitches (d = 9). The diagrams for windings of the first classification have the reference points determined by Fig. 8-25. For windings with d = 9, the reference points are determined by Fig. 7-44 when the sign of a is positive, and by Fig. 7-45 when the sign of a is negative. The sequence and position of the starts and ends of the winding parts are then determined by the use of the Connection Tables as explained in Art. 7-3. These Tables also show the permissible number of parallel paths and the star and delta connection. Working Diagrams are given for the slot and pole combinations shown in Table 8-25. In this Table, 8-1, 8-2, etc., indicate the figures which represent the corresponding Working Diagrams.


C
A
B
Beginning of the Coil Series A_1 of Phase A
End of a Coil Series of Phase A

A = A_1 = Top of slot 1
B = Bottom of slot (1 + back pitch)
C = Bottom of slot (1 + number of slots - front pitch)

Fig. 8-25. General Working Diagram for determining the reference points for windings with d = 3 and d = 6.

Fully developed Winding Diagrams are also given for the folowing cases:

84	slots	12 poles	spp = 2 1/3
117	slots	18 poles	spp = 2 1/6
114	slots	18 poles	spp = 2 1/9

8-4. Winding Pitch, Back Pitch, and Front Pitch. General Rules. The formula for the winding pitch is the same as that given for balanced fractional-slot wave windings (see Art. 7-4), namely,

$$\text{winding pitch} = 6I + \frac{6n + a}{d} \tag{8-1}$$

where I is the integer of spp, n the numerator of the fraction of spp, and d its denominator. For example, when spp = 2 1/9, I is equal to 2, n is equal to 1, and d to 9. a is again the smallest integer which makes the winding pitch an integer. Therefore, for spp = 2 1/9, a = + 3 and the winding pitch = $6 \times 2 + \frac{6 \times 1 + 3}{9} = 13$. a can be equal to 0.

When the same magnitude of a with positive and negative sign makes the quantity $\frac{(6n + a)}{d}$ an integer, choose the sign which makes this quantity an even number.

The values of $\frac{(6n + a)}{d}$ and a for different values of $\frac{n}{d}$ are given in Table 8-24. It can be seen from this Table that for d equal 3 to 12, a has the magnitudes 0, 3, and 6. a = 0 means that the winding is to be treated as an integral-slot winding for which d = 1 and a = 0. Thus, the windings with a = 0, i.e., the windings with d = 3 and d = 6, will be wound in coil series with abnormal-front pitches (see Art. 6-1). The windings with a larger than 0 have no abnormal-front pitches, just as the balanced fractional-slot wave windings have no abnormal-front pitches (Art. 7-1); however, their layout is somewhat different from that of the latter windings.

When a = 0, each phase consists of 2 parts, just as in the case of the integral-slot winding.

When a is larger than 0, its magnitude determines the number of parts in each phase; there are $\left(\frac{(\text{No. of poles})}{d}\right) \times a$ parts in each phase. Furthermore, as in the case of the balanced fractional-slot wave windings, the plus sign before a means that the winding progresses clockwise with all parts starting with upper conductors, and the minus sign before a means that the winding progresses counter-clockwise with all parts starting with lower conductors.

The layout of the unbalanced fractional-slot wave windings is based on its D-series, just as in the case of the balanced fractional-slot wave windings. However, the shape of the D-series of the unbalanced windings has more variety than that of the balanced windings. The magnitude of D is given by the equation

$$D = \frac{3NP + 3}{d} \qquad (8\text{-}2)$$

where N is the numerator of spp, and P the smallest integer, including zero, which makes D an integer. For example, for spp = 2 1/9 = $\frac{19}{9}$, N = 19, P = 2, and D = 13.

The rules for layout of unbalanced fractional-slot wave windings which are common to all windings of this kind are:

a. Write spp = $\frac{N}{d}$ where N and d have no common divisor.

b. Determine the value of D from Eq. 8-2.

c. Write first the D-series

$$1, \quad 1 + D, \quad 1 + 2D, \ \ldots \quad 1 + (N - 1)D \qquad (8\text{-}3)$$

for N digits, all being smaller than N, i.e., subtract N or a multiple of it, if any of the numbers become larger than N. Then below the D-series write $\left(\frac{S}{N} - 1\right)$ more series in such a manner that the numbers of each of the $\frac{S}{N}$ series are larger by N than the numbers of the foregoing series. The $\frac{S}{N}$ horizontal rows obtained in this manner represent the slots of the whole machine.

For maximum distribution factor of the main wave, the assignment of the slots to the 3 phases should be the same as that for unbalanced lap windings (see Art. 5-4), i.e., the $\frac{S}{N}$ series should be divided into 3 groups in such a manner that the slots belonging to each group are as close to one another as possible and that each group has the same number of slots (when the number of slots is not divisible by 3, a certain number of coils are to be left out (see Art. 8-8). The application of this rule to wave windings makes it necessary to treat these windings individually corresponding to the value of the denominator of the fraction d. This will be explained by several examples in which S is divisible as well as not divisible by 3. Independent of the value of d, the parts of each phase must follow the winding-pitch series (see Art. 7-4).

Whether or not the parts of each phase can be connected in parallel is to be decided from case to case in the same manner as was done for unbalanced fractional-slot lap windings (see Art. 5-5).

8-5. Layout of a Winding with a Number of Slots Divisible by 3 and the Denominator of spp = 3. It follows from Table 8-24 that, in this case, a = 0. Further, Eq. 8-1 yields

winding pitch = 2N, back pitch = front pitch = N

a = 0 means that the winding can be connected in the same manner as the integral-slot wave windings, i.e., in coil series and with abnormal-front pitches. In the D-series determined according to (c) Art. 8-4, consecutive numbers of each horizontal row differ by D and consecutive numbers of each vertical row differ by N. Since the winding pitch equals 2N, the numbers which follow the winding-pitch series

1, 1 + (winding pitch), 1 + 2 x (winding pitch)...

are the alternate numbers of the vertical rows.

As in the case of integral-slot windings, each phase consists of 2 parts independent of the number of poles. Since the number of slots S is always divisible by 6, the 6 parts of the winding can always be made equal, i.e., the 2 parts of each phase can always be made equal. The formulae given below for the starts and ends of the winding parts, as well as the treatment of the example, are based on equal winding parts. It should be noted that the 2 parts of each phase can also be made with unequal numbers of coils, as is shown in Art. 8-6 for the windings with d = 6. Making both parts of each phase with equal numbers of coils has the advantage that both parts can be connected not only in series but also in parallel; making both parts with unequal numbers of coils has the advantage that the number of abnormal-front pitch is smaller than in the case of equal numbers of coils, but parallel connection of the 2 parts is not possible.

Each coil series consists here of $\frac{S}{2N}$ coils, i.e., of $\frac{S}{2N}$ upper conductors and $\frac{S}{2N}$ lower conductors. Therefore, in order to lay out the winding, start with upper conductor 1 and wind the first coil series of $\frac{S}{2N}$ coils, observing that the back pitch = front pitch = N. Then connect the last conductor of the first coil series which is a lower conductor with upper conductor 2 and wind the second coil series; the last conductor of this series connects with upper conductor 3 and so forth, until 1/6 of all conductors are connected together. This is then the first part of phase A. Start now with the upper conductor which is one front pitch apart from the last lower conductor of the first part of phase A and wind again a sixth of the conductors. This is part 1 of phase C. Part 1 of phase B is obtained by one sixth more of the conductors in the same manner. The next sixth then is the second part of phase A and so forth.

The starts and the ends of the parts are, with the abbreviation

$$\left(\frac{S}{6} - 1\right) \times \text{winding pitch} + \text{back pitch} = b \qquad (8\text{-}4)$$

as follows:

$$\begin{aligned} A_1 &= 1 & A_2 &= 1 + b + \tfrac{N}{3}i \\ A_3 &= 1 + N & A_4 &= A_3 + b + \tfrac{N}{3}i \\ C_1 &= A_2 + \text{front pitch} & C_2 &= C_1 + b + \tfrac{2N}{3}i - \tfrac{N}{3}i \\ C_3 &= C_1 + N & C_4 &= C_3 + b + \tfrac{2N}{3}i - \tfrac{N}{3}i \\ B_1 &= C_2 + \text{front pitch} & B_2 &= B_1 + b + (N - 1) - \tfrac{2N}{3}i \\ B_3 &= B_1 + N & B_4 &= B_3 + b + (N - 1) - \tfrac{2N}{3}i \end{aligned} \qquad (8\text{-}5)$$

The letter i indicates that only the integral part of the quantity is to be taken. If any of the quantities A_2, A_4, C_1, etc., become larger than the number of slots S, this latter quantity or a multiple of it is to be subtracted. The number of longer-front pitches is equal to

$\frac{N}{3}i$ in both groups of phase A

$\frac{2N}{3}i - \frac{N}{3}i$ in both groups of phase C

$(N-1) - \frac{2N}{3}i$ in both groups of phase B

The total number of longer-front pitches is equal to 2(N - 1).

Example

The method described will be demonstrated by a 12-pole winding in 96 slots with 2 conductors per slot. The Master Table 3-5 yields for 12 poles and 96 slots spp = 2 2/3 = 8/3. Thus, N = 8, d = 3, and n = 2. Table 8-24 shows that, for 2/3, $\left(\frac{6n + a}{d}\right) = 4$, and a = 0. The winding pitch is 6 x 2 + 4 = 16 and back pitch = front pitch = 8. From Eq. 8-2

$$3 \times 8 \times P + 3 \qquad 1 \text{ with } P = 0$$

i.e., the D-series consists of N = 8 digits increasing by 1. The number of D-series is $\frac{S}{N} = \frac{96}{8} = 12$. The numbers of the consecutive figures of a vertical row differ by N = 8. Thus, the rules (a) to (c) of Art. 8-4 yield the following D-series:

	A			C		B	
1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56
57	58	59	60	61	62	63	64
65	66	67	68	69	70	71	72
73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88
89	90	91	92	93	94	95	96

D-series

These series represent all of the slots (or all upper conductors, or all lower conductors) of the machine.

Phase A will start with upper conductor 1. This conductor is to be connected with lower conductor 1 + 8 = 9, and this latter conductor with the upper conductor 9 + 8 = 17 = 1 + winding pitch = 1 + 2N. Since consecutive digits of each column differ by N, the first upper conductor which follows upper conductor 1 is the third digit (17) of the first column. The next following upper conductor (33) is then the fifth digit of the first column, and so forth. The first column consisting of $\frac{S}{N} = \frac{96}{8} = 12$ digits supplies thus $\frac{S}{2N} = 6$ consecutive upper conductors 1, 17, 33, 49, 65 and 81, which make the first coil-series of phase A. The last upper conductor of this coil series is 81, and the lower conductor to which this conductor is connected is 81 + 8 = 89. Now the front pitch must be increased by 1, i.e., the lower conductor 89 must be connected with upper conductor 89 + 8 + 1 = 98 - 96 = 2. This is the first conductor of the second column. Starting with this conductor the second coil series consisting of 6 coils is wound; then, again increasing the front pitch by 1, the third coil series is wound starting with upper conductor 3 and so forth until a sixth of all coils are included. This is then the first part of phase A, with the start A_1 and the end A_2 which are upper and lower conductors, respectively. The next upper conductor which follows A_2 is the start C_1 of phase C which is to be wound in the same manner as phase A, until the second sixth of all coils are included. The third sixth constitutes the first part of phase B, the fourth sixth the second part of phase A, the fifth sixth the second part of phase C, and finally the sixth sixth the second part of phase B. The sequence of the upper conductors (or slots) is then as follows:

A_1	1	17	33	49	65	81	2	18	34	50	66	82	3	19	35	51	y-series
A_3	9	25	41	57	73	89	10	26	42	58	74	90	11	27	43	59	
C_1	67	83	4	20	36	52	68	84	5	21	37	53	69	85	6	22	
C_3	75	91	12	28	44	60	76	92	13	29	45	61	77	93	14	30	
B_1	38	54	70	86	7	23	39	55	71	87	8	24	40	56	72	88	
B_3	46	62	78	94	15	31	47	63	79	95	16	32	48	64	80	96	

These are winding-pitch series. Long-front pitches appear before the starts of the coil series, i.e., before the conductors of the first two horizontal rows of the D-series, except conductors 1 and 9, which are starts of parts A_1-A_2 and A_3-A_4. There are $2 \times N - 2 = 14$ abnormal-front pitches. The spacing between them, with the 2 exceptions, is equal to the number of coils in a coil series, i.e., 6.

From the connection chart (winding-pitch series)

$A_1 = 1 \quad A_2 = 51 + 8 = 59 \quad C_1 = 67 \quad C_2 = 22 + 8 = 30$

$B_1 = 38 \quad B_2 = 88 + 8 = 96 \quad A_3 = 9 \quad A_4 = 59 + 8 = 67$

$C_3 = 75 \quad C_4 = 30 + 8 = 38 \quad B_3 = 46 \quad B_4 = 96 + 8 - 96 = 8$

The formulae (8-4) and (8-5) yield the same results. Checking, for example, C_4:

$$b = \left(\frac{96}{6} - 1\right) \times 16 + 8 = 248$$

$$C_4 = 75 + 248 + 5 - 2 = 326 - 3 \times 96 = 38$$

The broken lines shown in the D-series indicate the separation of the D-series in the slots of the 3 phases. The slots to the left belong to phase A; the slots in the middle to phase C, and those to the right to phase B. A comparison of this distribution with those shown in Art.5-4 for unbalanced fractional-slot lap windings indicates that here also maximum distribution factor results.

An examination of the connection chart (winding-pitch series) shows that both parts of each phase can be connected in parallel. This follows from the fact that the conductors of part A_3-A_4 (or C_3-C_4, or B_3-B_4) which correspond to the conductors of part A_1-A_2 (or C_1-C_2 or B_1-B_2) in the winding-pitch series lie in the same column of the D-series (see Art. 5-5). Considering, for example, phase A, the corresponding conductors 1 and 9 both lie in the first column, the corresponding conductors 18 and 26 both lie in the second column, and so forth.

For series as well as for parallel connection of the parts, the polarities of the starts (or ends) must be known. Note that in the case of d = 3, the polarities of A_1 and A_3 (C_1 and C_3, B_1 and B_3) are opposite. The same applies to the ends of the two parts of each phase. Thus, for series connection, connect A_2 with A_4, C_2 with C_4, and B_2 with B_4. A_1, A_3, C_1, C_3, B_1, and B_3 are the leads. For parallel connection, connect A_1 with A_4, A_3 with A_2, C_1 with C_4, C_3 with C_2, B_1 with B_4, and B_3 with B_2. For star connection of the 3 phases, A_3 must be connected with B_3 and C_1 to the star point; for delta connection, A_3 must be connected with B_1, B_3 with C_3, and C_1 with A_1. This applies to the series as well as to the parallel connection of the 2 winding parts. In both cases, A_1, B_1, and C_3 are the leads to be connected to slip rings or to the line.

8-6. Layout of a Winding with a Number of Slots Divisible by 3 and the Denominator of spp = 6.

It follows from Table 8-24 that in this case a = 0. Further, Eq. 8-1 yields

$$\text{winding pitch} = N \qquad \text{back pitch} = \frac{(N-1)}{2}$$
$$\text{front pitch} = \frac{(N+1)}{2}$$

a = 0 means here, as in the case of d = 3, that the winding can be connected in the same manner as was the integral-slot wave winding , i.e., in coil series and with abnormal-front pitches. Since the winding pitch is equal to N and N is the difference between 2 consecutive digits of the vertical rows, the numbers which follow the winding-pitch series

1, 1 + (winding pitch), 1 + 2 x (winding pitch) ...

are the consecutive numbers of the vertical rows.

As in the cases for $d = 3$ for integral-slot wave windings, each phase consists of 2 parts independent of the number of poles. However, the number of slots is not always divisible by 6 and in such cases the 2 parts of each phase must have different numbers of coils. When the number of slots is divisible by 6, the winding can be accomplished with 6 equal parts as in the case of $d = 3$. Yet the advantage, which the arrangement of 6 equal parts has in the case of $d = 3$, namely, the possibility of 2 parallel paths, does not exist here. For this reason, the formulae for the starts and ends of the winding parts given below, as well as the treatment of the example, are based on unequal winding parts, regardless of whether or not the number of slots is divisible by 6.

When the numerator n of the fraction of spp is equal to 1 (for example, $n = 1$ for spp = 1 1/6, 2 1/6, 3 1/6 ...) the second part of each phase will be made with $\frac{S}{3N}$ more coils than the first part. On the other hand, when, the numerator of the fraction of spp is equal to 5 (for example, $n = 5$ for spp = 1 5/6, 2 5/6, 3 5/6 ...), the second part of each phase will be made with $\frac{S}{3N}$ less coils than the first part. Thus, the numbers of coils contained in the 2 parts of each phase are

$$\begin{array}{l|l} \underline{n = 1} & \underline{n = 5} \\ \text{first part} = \frac{S}{6}\left(\frac{N-1}{N}\right) & \text{first part} = \frac{S}{6}\left(\frac{N+1}{N}\right) \\ \text{coils} & \text{coils} \\ \text{second part} = \frac{S}{6}\left(\frac{N+1}{N}\right) & \text{second part} = \frac{S}{6}\left(\frac{N-1}{N}\right) \\ \text{coils} & \text{coils} \end{array} \tag{8-6}$$

In order to accomplish the winding, start with upper conductor 1 and wind the first coil series of $\frac{S}{N}$ coils, observing that the back pitch is $\left(\frac{N-1}{2}\right)$ and the front pitch $\left(\frac{N+1}{2}\right)$. These first $\frac{S}{N}$ coils constitute the first column of the D-series. The last conductor of the first coil series, which is a lower conductor, connects with upper conductor 2 and makes up the second coil series, and so forth. Depending on whether n is 1 or 5, $\frac{S}{6}\left(\frac{N-1}{N}\right)$ or $\frac{S}{6}\left(\frac{N+1}{N}\right)$ coils are to be connected in this manner and this is then the first part of phase A. The first part of phase C starts 1 front pitch plus 1 ahead of the last lower conductor of the first part of phase A and has as many coils as the first part of phase A. The same applies to the first part of phase B with respect to phase C. After the first part of phase B has been accomplished, the second parts of the 3 phases are to be made up. The second part of phase A starts 1 front pitch plus 1 ahead of the last lower conductor of the first part of phase B and has $\frac{S}{6}\left(\frac{N+1}{N}\right)$ or $\frac{S}{6}\left(\frac{N-1}{N}\right)$ coils depending on whether n is 1 or 5. The second part of phase C starts in an upper conductor which is 1 front pitch ahead of the last lower conductor of the second part of phase A, and the second part of phase B starts in an upper conductor which is 1 front pitch ahead of the last lower conductor of the second part of phase C.

The starts and ends of the parts are as follows:

(a) n = 1. With the abbreviations,

$$\left(I\frac{S}{N} - 1\right) \times \text{winding pitch} + \text{back pitch} + I - 1 = b_{12} \qquad (8\text{-}7)$$

and

$$\left[(2 \times \text{spp} - I)\frac{S}{N} - 1\right] \times \text{winding pitch} + \text{back pitch} + (2 \times \text{spp} - I)_i = b_{14} \qquad (8\text{-}8)$$

where I is the integer of spp, and i again indicates that the integer of the quantity is to be taken,

$$\begin{array}{l|l}
A_1 = 1 & A_2 = 1 + b_{12} \\
C_1 = A_2 + \text{front pitch} + 1 & C_2 = 2A_2 + \text{front pitch} \\
B_1 = 2(A_2 + \text{front pitch}) + 1 & B_2 = 3A_2 + 2 \times \text{front pitch} \\
 & \qquad\qquad\qquad\qquad (8\text{-}9) \\
A_3 = 3(A_2 + \text{front pitch}) + 1 & A_4 = A_3 + b_{14} \\
C_3 = A_4 + \text{front pitch} & C_4 = 2A_4 - A_3 + \text{front pitch} \\
B_3 = 2(A_4 + \text{front pitch}) - A_3 & B_4 = 3A_4 - 2(A_3 - \text{front pitch})
\end{array}$$

The number of longer-front pitches is (I - 1) in the first winding parts, and I in the second winding parts. The total number of longer-front pitches is 3(2I - 1)

(b) n = 5. With the abbreviations,

$$\left[(I + 1)\frac{S}{N} - 1\right] \times \text{winding pitch} + \text{back pitch} + I = b_{52} \qquad (8\text{-}10)$$

$$\left[(2 \times \text{spp} - I - 1)\frac{S}{N} - 1\right] \times \text{winding pitch} + \text{back pitch} + (2 \times \text{spp} - I - 1)_i = b_{54} \qquad (8\text{-}11)$$

$A_1 = 1$ $\qquad$ $A_2 = 1 + b_{52}$

$C_1 = A_2 + \text{front pitch} + 1$ $\qquad$ $C_2 = 2A_2 + \text{front pitch}$

$B_1 = 2(A_2 + \text{front pitch}) + 1$ $\qquad$ $B_2 = 3A_2 + 2 \times \text{front pitch}$

$$A_3 = 3(A_2 + \text{front pitch}) + 1 \qquad A_4 = A_3 + b_{54} \tag{8-12}$$

$C_3 = A_4 + \text{front pitch}$ $\qquad$ $C_4 = 2A_4 - A_3 + \text{front pitch} + 1$

$B_3 = 2(A_4 + \text{front pitch}) - A_3 + 1$ $\qquad$ $B_4 = 3A_4 - 2(A_3 - \text{front pitch}) + 1$

If any one of these quantities becomes larger than S, this latter quantity or a multiple of it is to be subtracted. The number of longer-front pitches is equal to I in the parts A_1-A_2, C_1-C_2, B_1-B_2, A_3-A_4, and B_3-B_4; it is equal to (I + 1) in the winding part C_3-C_4. The total number of abnormal-front pitches is equal to (6I + 1)

Example

The method described will be demonstrated by a 12-pole winding in 102 slots with 2 conductors per slot. The Master Table 3-5 yields for 12 poles and 102 slots spp = 2 5/6 = $\frac{17}{6}$. Thus, N = 17, d = 6, and n = 5. Table 8-24 shows that, for 5/6, $\frac{(6n + a)}{d} = 5$ and a = 0. The winding pitch is then 6 x 2 + 5 = = 17 = N; the back pitch = $\frac{(17 - 1)}{2} = 8$, and the front pitch = $\frac{(17 + 1)}{2} = 9$.

From Eq. 8-2

$$D = \frac{3 \times 17 \times P + 3}{6} = 9 \text{ with } P = 1$$

This yields, according to rule (c) of Art. 8-4, the following D-series:

			A						C					B		
1	10	2	11	3	12	4	13	5	14	6	15	7	16	8	17	9
18	27	19	28	20	29	21	30	22	31	23	32	24	33	25	34	26
35	44	36	45	37	46	38	47	39	48	40	49	41	50	42	51	43
52	61	53	62	54	63	55	64	56	65	57	66	58	67	59	68	60
69	78	70	79	71	80	72	81	73	82	74	83	75	84	76	85	77
86	95	87	96	88	97	89	98	90	99	91	100	92	101	93	102	94

D-series

Each horizontal row contains N = 17 numbers (conductors), and there are $\frac{S}{N} = \frac{102}{17} = 6$ horizontal rows. Each column contains 6 conductors following the winding-pitch series

1, 1 + 17 = 18, 18 + 17 = 35, 35 + 17 = 52, ...

The connection chart (winding-pitch series), i.e., the sequence of the upper conductors, corresponding to the rules given previously in this article (see also Art. 8-5) is as follows:

A_1	1	18	35	52	69	86	2	19	36	53	70	87	3	20	37	54	71	88
A_3	10	27	44	61	78	95	11	28	45	62	79	96	12	29	46	63		
C_1	4	21	38	55	72	89	5	22	39	56	73	90	6	23	40	57	74	91
C_3	80	97	13	30	47	64	81	98	14	31	48	65	82	99	15	32		
B_1	7	24	41	58	75	92	8	25	42	59	76	93	9	26	43	60	77	94
B_3	49	66	83	100	16	33	50	67	84	101	17	34	51	68	85	102		

y-series

Since n is equal to 5, the first part of each phase contains $\frac{102}{6}\left(\frac{17+1}{17}\right) = 18$ coils and the second part of each phase contains $\frac{102}{6}\left(\frac{17-1}{17}\right) = 16$ coils. Starting with upper conductor 1, the conductors are connected continuously, observing that the back pitch is equal to 8 and the front pitch to 9. The first 18 coils are then assigned to part 1 of phase A, the next 18 coils to part 1 of phase C and the next 18 coils to part 1 of phase B. The 16 coils following part 1 of phase B constitute the second part of phase A; then 16 coils follow for part 2 of phase C, and finally 16 coils for part 2 of phase B.

There are 6 x 2 + 1 = 13 longer-front pitches, 3 in part C_3-C_4, and 2 in each of the other 5 parts. The longer pitches appear before the starts of the coil series, except when these starts coincide with the starts of a winding part. Here, longer-front pitches will be found before the upper conductors 2, 3, 5, 6, 8, 9, 11, 12, 13, 14, 15, 16, and 17.

From the Connection chart (winding-pitch series):

$A_1 = 1$ $A_2 = 88 + 8 = 96$

$A_3 = 10$ $A_4 = 63 + 8 = 71$

$C_1 = 4$ $C_2 = 91 + 8 = 99$

$C_3 = 80$ $C_4 = 32 + 8 = 40$

$B_1 = 7$ $B_2 = 94 + 8 = 102$

$B_3 = 49$ $B_4 = 102 + 8 = 110 - 102 = 8$

The formulae 8-10 to 8-12 yield the same results. Checking C_4, for example,

$b_{52} = \left(3 \times \frac{102}{17} - 1 \right) \times 17 + 8 + 2 = 299$

$b_{54} = \left((2 \times 2\ 5/6 - 2 - 1) \times \frac{102}{17} - 1\right) \times 17 + 8 + 2 = 265$

$A_2 = 1 + 299 - 2 \times 102 = 96$

$A_3 = 3(96 + 9) + 1 = 316 - 3 \times 102 = 10$

$A_4 = 10 + 265 - 2 \times 102 = 71$

$C_4 = 2 \times 71 - 10 + 9 + 1 = 142 - 102 = 40$

The slots of the 3 phases were obtained by separating the D-series with the broken lines shown. This distribution of the slots among the 3 phases yields maximum distribution factor of the main wave.

An examination of the connection chart (winding-pitch series) shows that the 2 parts of the phase cannot be connected in parallel because they consist of different numbers of coils. In the case considered, the number of slots (102) is divisible by 6 and, therefore, the 2 parts of each phase could be made with equal numbers of coils $\frac{102}{6} = 17$, but even then the 2 parallel circuits would not be possible because the corresponding slots of the 2 parts of the phase do not lie in the same columns of the D-series (see Art. 8-5).

For series connection, observe that the polarities of A_1 and A_3 (C_1 and C_3, B_1 and B_3) are opposite. Thus, A_2 is to be connected with A_4, C_2 with C_4, and B_2 with B_4. A_1, A_3, C_1, C_3, B_1, and B_3 are the leads.

A_1, B_1, and C_3 are to be used as phase beginnings.

The Working Diagram for the foregoing example is shown in Fig.8-15 and the proper connection of the winding parts is given by Table 8-15.

A practical example of a wave winding with spp = 5 5/6 is shown in Fig. 8-18a. This shows the lead or connection end of a 12-pole wave wound rotor with 210 slots. Fig. 8-18 is the Working Diagram. The rotor winding is connected single-circuit delta by using Table 8-18.

8-7. Layout of a Winding with a Number of Slots Divisible by 3 and the Denominator of spp = 9. It follows from Table 8-24 that in this case a = ± 3. Furthermore, from Eqs. 8-1 and 8-2,

$$\begin{array}{ll} \text{Winding pitch} = D & \text{when a is positive} \\ \text{Winding pitch} = N - D & \text{when a is negative} \end{array} \qquad (8\text{-}13)$$

a = ± 3 means that the winding has the features of the balanced fractional-slot wave windings. (See Art. 7-4.) Thus, the number of parts in each phase is equal to $\left(\frac{(\text{No. of poles})}{d} \times a\right)$. The winding pitch depends upon the magnitude of D. Since D is the difference between consecutive numbers in the horizontal rows of the D-series, the numbers which follow the winding-pitch series will be found in consecutive columns and not in the same column as is the case when d = 3 or d = 6. The winding has no abnormal-front pitches.

In order to lay out the winding, the D-series is first set up according to the rules (a) to (c) of Art. 8-4. There will be $\frac{S}{N}$ horizontal rows with N slots each, containing all slots of the winding. Then, from the D-series, the connection chart (winding-pitch series) is to be determined in the same way as for balanced fractional-slot wave windings (Art. 7-9), namely, as follows:

When a is positive, start with conductor 1 and find in consecutive columns N numbers which follow the winding-pitch series

1, 1 + (winding pitch), 1 + 2 x (winding pitch), ...(8-14)

This is the first horizontal row of the connection chart. Start now with the (1 + N)th conductor which follows conductor 1 in the first column of the D-series and again find N numbers which follow the same winding-pitch series. This is then the second horizontal row of the connection chart. Continue in the same way with the third, fourth... conductor of the first column of the D-series until $\frac{S}{N}$ horizontal rows, all following the winding-pitch series (Eq. 8-14), are obtained. The connection chart (winding-pitch series) determined in this manner represents upper conductors. The winding progresses clockwise.

When a is negative, start with conductor 1 and find in consecutive columns N numbers which follows the winding-pitch series

$$\begin{array}{l} 1,\ 1 + S - (\text{winding pitch}), \\ 1 + S - 2 \times (\text{winding pitch}),\ \ldots \end{array} \qquad (8\text{-}15)$$

This is the first horizontal row of the connection chart. Start now with the (1 + N)th conductor which follows conductor 1 in the first column of the D-series and again find N numbers which follow the winding-pitch series (8-15), and so forth, until $\frac{S}{N}$ horizontal rows are obtained. The connection chart (winding-pitch series) determined in this manner represents lower conductors. The winding progresses counter-clockwise.

With the connection chart determined, the next step is to assign in this chart the slots (or upper or lower conductors) to the 3 phases. Two cases are to be distinguished.

(a)

$$\frac{N}{3} = \text{integer} + 1/3 = I' + 1/3$$

In this case, assign the following numbers of slots to the 3 phases:

$$\begin{array}{lccc} & A & C & B \\ \text{First horizontal row} & \frac{(N+2)}{3} & \frac{(N-1)}{3} & \frac{(N-1)}{3} \\ \text{Second horizontal row} & \frac{(N-1)}{3} & \frac{(N+2)}{3} & \frac{(N-1)}{3} \\ \text{Third horizontal row} & \frac{(N-1)}{3} & \frac{(N-1)}{3} & \frac{(N+2)}{3} \end{array} \qquad (8\text{-}16)$$

Repeat the same for each following 3 horizontal rows.

Each group of 3 horizontal rows in the connection chart yields 3 winding parts for each phase. The winding parts due to the first 3 horizontal rows will be denoted by

$$\begin{array}{ccc} A1_1\text{-}A1_2 & C1_1\text{-}C1_2 & B1_1\text{-}B1_2 \\ A2_1\text{-}A2_2 & C2_1\text{-}C2_2 & B2_1\text{-}B2_2 \\ A3_1\text{-}A3_2 & C3_1\text{-}C3_2 & B3_1\text{-}B3_2 \end{array}$$

The winding parts derived from the 4th, 5th, and 6th horizontal rows of the connection chart will be denoted by

$$\begin{array}{ccc} A1_3\text{-}A1_4 & C1_3\text{-}C1_4 & B1_3\text{-}B1_4 \\ A2_3\text{-}A2_4 & C2_3\text{-}C2_4 & B2_3\text{-}B2_4 \\ A3_3\text{-}A3_4 & C3_3\text{-}C3_4 & B3_3\text{-}B3_4 \end{array}$$

and so forth. The starts and ends of the winding parts are then as follows:

$a = +3$	$a = -3$
$A1_1 = 1$	$A1_1 = 1$
$A1_2 = 1 + I' \times$ (winding pitch) + back pitch	$A1_2 = 1 + S - I' \times$ (winding pitch) - back pitch

$$\begin{aligned}
C1_1 &= A1_2 + \text{front pitch}\\
C1_2 &= C1_1 + (I' - 1) \times \text{(winding pitch)} + \text{back pitch}\\
B1_1 &= C1_2 + \text{front pitch}\\
B1_2 &= B1_1 + C1_2 - C1_1\\[1ex]
A2_1 &= 1 + N\\
A2_2 &= A2_1 + C1_2 - C1_1\\
C2_1 &= A2_2 + \text{front pitch}\\
C2_2 &= C2_1 + A1_2 - A1_1\\
B2_1 &= C2_2 + \text{front pitch}\\
B2_2 &= B2_1 + C1_2 - C1_1\\[1ex]
A3_1 &= 1 + 2N\\
A3_2 &= A3_1 + C1_2 - C1_1\\
C3_1 &= A3_2 + \text{front pitch}\\
C3_2 &= C3_1 + C1_2 - C1_1\\
B3_1 &= C3_2 + \text{front pitch}\\
B3_2 &= B3_1 + A1_2 - A1_1
\end{aligned} \tag{8-17}$$

$$\begin{aligned}
C1_1 &= A1_2 - \text{front pitch}\\
C1_2 &= C1_1 + S - (I' - 1) \times \text{(winding pitch)} - \text{back pitch}\\
B1_1 &= C1_2 - \text{front pitch}\\
B1_2 &= B1_1 + C1_2 - C1_1\\[1ex]
A2_1 &= 1 + N\\
A2_2 &= A2_1 + C1_2 - C1_1\\
C2_1 &= A2_2 - \text{front pitch}\\
C2_2 &= C2_1 + A1_2 - A1_1\\
B2_1 &= C2_2 - \text{front pitch}\\
B2_2 &= B2_1 + C1_2 - C1_1\\[1ex]
A3_1 &= 1 + 2N\\
A3_2 &= A3_1 + C1_2 - C1_1\\
C3_1 &= A3_2 - \text{front pitch}\\
C3_2 &= C3_1 + C1_2 - C1_1\\
B3_1 &= C3_2 - \text{front pitch}\\
B3_2 &= B3_1 + A1_2 - A1_1
\end{aligned} \tag{8-18}$$

The starts and ends with the subscripts 3 and 4 are obtained from those with the subscripts 1 and 2 by adding 3N. Thus for example,

$$\begin{aligned}
A1_3 &= A1_1 + 3N & \qquad A1_4 &= A1_2 + 3N\\
A2_3 &= A2_1 + 3N & \qquad A2_4 &= A2_2 + 3N
\end{aligned} \tag{8-19}$$

and so forth. This applies to positive as well as to negative a. If any of the quantities $A1_2$, $C1_1$, $C1_2$, etc., becomes larger than the number of slots S, this latter or a multiple of it is to be subtracted. If any of the quantities becomes negative, add S. When a = + 3, all starts (subscripts 1, 3, 5, ...) are upper conductors, and all ends (subscripts 2, 4, 6, ...) are lower conductors. When a = - 3, the opposite is true.

(b)

$$\frac{N}{3} = \text{integer} + 2/3 = I' + 2/3$$

In this case assign in the connection chart (winding-pitch series) the following numbers of slots to the 3 phases:

	A	C	B
First horizontal row	$\frac{(N + 1)}{3}$	$\frac{(N - 2)}{3}$	$\frac{(N + 1)}{3}$
Second horizontal row	$\frac{(N - 2)}{3}$	$\frac{(N + 1)}{3}$	$\frac{(N + 1)}{3}$
Third horizontal row	$\frac{(N + 1)}{3}$	$\frac{(N + 1)}{3}$	$\frac{(N - 2)}{3}$

(8-20)

Repeat the same for each following 3 horizontal rows.

As in the case (a), each 3 horizontal rows of the connection chart yield 3 winding parts for each phase. With the same notations as under (a), the starts and ends of the winding parts are:

$a = +3$

$A1_1 = 1$

$A1_2 = 1 - I' \times (\text{winding pitch}) + \text{back pitch}$

$C1_1 = A1_2 + \text{front pitch}$

$C1_2 = C1_1 + (I' - 1) \times (\text{winding pitch}) + \text{back pitch}$

$B1_1 = C1_2 + \text{front pitch}$

$B1_2 = B1_1 + A1_2 - A1_1$

$A2_1 = 1 + N$

$A2_2 = A2_1 + C1_2 - C1_1$

$C2_1 = A2_2 + \text{front pitch}$

$C2_2 = C2_1 + A1_2 - A1_1$ (8-21)

$B2_1 = C2_2 + \text{front pitch}$

$B2_2 = B2_1 + A1_2 - A1_1$

$A3_1 = 1 + 2N$

$A3_2 = A3_1 + A1_2 - A1_1$

$C3_1 = A3_2 + \text{front pitch}$

$C3_2 = C3_1 + A1_2 - A1_1$

$B3_1 = C3_2 + \text{front pitch}$

$B3_2 = B3_1 + C1_2 - C1_1$

$a = -3$

$A1_1 = 1$

$A1_2 = 1 + S - I' \times (\text{winding pitch}) - \text{back pitch}$

$C1_1 = A1_2 - \text{front pitch}$

$C1_2 = C1_1 + S - (I' - 1) \times (\text{winding pitch}) - \text{back pitch}$

$B1_1 = C1_2 - \text{front pitch}$

$B1_2 = B1_1 + A1_2 - A1_1$

$A2_1 = 1 + N$

$A2_2 = A2_1 + C1_2 - C1_1$

$C2_1 = A2_2 - \text{front pitch}$

$C2_2 = C2_1 + A1_2 - A1_1$ (8-22)

$B2_1 = C2_2 - \text{front pitch}$

$B2_2 = B2_1 + A1_2 - A1_1$

$A3_1 = 1 + 2N$

$A3_2 = A3_1 + A1_2 - A1_1$

$C3_1 = A3_2 - \text{front pitch}$

$C3_2 = C3_1 + A1_2 - A1_1$

$B3_1 = C3_2 - \text{front pitch}$

$B3_2 = B3_1 + C1_2 - C1_1$

The starts and ends with the subscripts 3 and 4 are obtained from those with the subscripts 1 and 2 by adding 3N in the same manner, as under (a). If any of the quantities $A1_2$, $A2_1$, $A2_2$, etc., become larger than the number of slots S, this latter or a multiple of it is to be subtracted.

The remarks made under (a) about the influence of the sign of a apply here also.

Example

The method described will be demonstrated on an 18-pole winding in 114 slots with 2 conductors per slot. The Master Table 3-5 yields for 18 poles and 114 slots spp = 2 1/9 = $\frac{19}{9}$. Thus, N = 19, d = 9, and n = 1. Table 8-24 shows that for 1/9, $\frac{(6n + a)}{d} = 1$ and a = + 3. The winding pitch is then 6 x 2 + 1 = 13, the back pitch = 6, and front pitch = 7. From Eq. 8-2

$$D = \frac{3 \times 19 \times P + 3}{9} = 13 \text{ with } P = 2$$

i.e., winding pitch = D.

Applying rule (c) of Art. 8-4, the following D-series is obtained:

		A							C						B				
1	14	8	2	15	9	3	16	10	4	17	11	5	18	12	6	19	13	7	
20	33	27	21	34	28	22	35	29	23	36	30	24	37	31	25	38	32	26	
39	52	46	40	53	47	41	54	48	42	55	49	43	56	50	44	57	51	45	D-series
58	71	65	59	72	66	60	73	67	61	74	68	62	75	69	63	76	70	64	
77	90	84	78	91	85	79	92	86	80	93	87	81	94	88	82	95	89	83	
96	109	103	97	110	104	98	111	105	99	112	106	100	113	107	101	114	108	102	

Each horizontal row contains N = 19 numbers (slots or conductors), and there are $\frac{S}{N} = \frac{114}{19} = 6$ horizontal rows. The connection chart (winding-pitch series) corresponding to the rules given previously in this article (see also Art. 7-9) is as follows:

				A							C						B		
$A1_1$	1	14	27	40	53	66	79	92	105	4	17	30	43	56	69	82	95	108	7
$A2_1$	20	33	46	59	72	85	98	111	10	23	36	49	62	75	88	101	114	13	26
$A3_1$	39	52	65	78	91	104	3	16	29	42	55	68	81	94	107	6	19	32	45
$A1_3$	58	71	84	97	110	9	22	35	48	61	74	87	100	113	12	25	38	51	64
$A2_3$	77	90	103	2	15	28	41	54	67	80	93	106	5	18	31	44	57	70	83
$A3_3$	96	109	8	21	34	47	60	73	86	99	112	11	24	37	50	63	76	89	102

y-series

Since $\frac{N}{3} = 6\ 1/3$ is equal to an integer + 1/3, the distribution of the slots or conductors among the 3 phases must correspond to the rule given under (a), i.e., the following number of conductors must be assigned to the 3 phases in the first 3 horizontal rows of the connection chart:

	A	C	B
In the 1st horizontal row	7	6	6
In the 2nd horizontal row	6	7	6
In the 3rd horizontal row	6	6	7

In the following 3 horizontal rows, the distribution must be the same as in the first 3 horizontal rows. The broken line in the connection chart indicates this distribution. Each phase consists of $\frac{(\text{No. of poles})}{d} \times a = \frac{18}{9} \times 3 = 6$ parts. Their starts and ends are:

$A1_1 = 1$ $A1_2 = 79 + 6 = 85$ $C1_1 = 92$ $C1_2 = 43 + 6 = 49$ $B1_1 = 56$ $B1_2 = 7 + 6 = 13$

$A2_1 = 20$ $A2_2 = 85 + 6 = 91$ $C2_1 = 98$ $C2_2 = 62 + 6 = 68$ $B2_1 = 75$ $B2_2 = 26 + 6 = 32$

$A3_1 = 39$ $A3_2 = 104 + 6 = 110$ $C3_1 = 3$ $C3_2 = 68 + 6 = 74$ $B3_1 = 81$ $B3_2 = 45 + 6 = 51$

$A1_3 = 58$ $A1_4 = 22 + 6 = 28$ $C1_3 = 35$ $C1_4 = 100 + 6 = 106$ $B1_3 = 113$ $B1_4 = 64 + 6 = 70$

$A2_3 = 77$ $A2_4 = 28 + 6 = 34$ $C2_3 = 41$ $C2_4 = 5 + 6 = 11$ $B2_3 = 18$ $B2_4 = 83 + 6 = 89$

$A3_3 = 96$ $A3_4 = 47 + 6 = 53$ $C3_3 = 60$ $C3_4 = 11 + 6 = 17$ $B3_3 = 24$ $B3_4 = 102 + 6 = 108$

The formulae given under (a) for a = + 3 (Eq. 8-17) yield the same results. Checking $B2_4$, for example:

$$A1_2 = 1 + 6 \times 13 + 6 = 85$$

$$C1_1 = 85 + 7 = 92$$

$$C1_2 = 92 + 5 \times 13 + 6 - 114 = 49$$

$$A2_1 = 1 + 19 = 20$$

$$A2_2 = 20 + 49 - 92 + 114 = 91$$

$$C2_1 = 91 + 7 = 98$$

$$C2_2 = 98 + 85 - 1 - 114 = 68$$

$$B2_1 = 68 + 7 = 75$$

$$B2_2 = 75 + 49 - 92 = 32$$

$$B2_4 = 32 + 3 \times 19 = 89$$

In order to connect the 6 parts of each phase in series or parallel, the polarities of the starts must be known. They are given for phase A in Fig. 8-24. The same relation of polarities exists also for phases C and B.

The parts $A1_1$-$A1_2$, $A2_1$-$A2_2$, and $A3_1$-$A3_2$ must be connected in series because they have different numbers of coils. Corresponding to Fig. 8-24, $A1_2$ must be connected with $A2_2$, and $A2_1$ with $A3_1$. Similarly, $A1_4$ must be connected with $A2_4$, and $A2_3$ with $A3_3$. The Connection Table of this winding is Table 8-20, and the Working Diagram is Fig. 8-20. The fully developed Winding Diagram is shown in Fig. 8-20a.

↑ $A1_1$	$A1_2$ ↓
↓ $A2_1$	$A2_2$ ↑
↑ $A3_1$	$A3_2$ ↓
↓ $A1_3$	$A1_4$ ↑
↑ $A2_3$	$A2_4$ ↓
↓ $A3_3$	$A3_4$ ↑

Fig. 8-24. Polarities of starts and ends of the parts of phase A of an 18-pole winding in 114 slots. spp = 2 1/9, d = 9, a = + 3

For the series connection of the 6 parts of phase A, $A3_2$ must be connected with $A3_4$, leaving $A1_1$ and $A1_3$ as leads. An examination of the winding-pitch series shows that 2 parallel circuits are possible, namely, the first 3 parts of each phase can be connected in parallel with the second 3 parts. This follows from the fact that corresponding conductors of these 2 groups with 3 parts each lie in the same columns of the D-series. Consider, for example, phase C. The 2 parts having 7 conductors in each of the 2nd and 5th horizontal rows lie in pairs above each other in the D-series. The same is true of the 2 parts having 6 conductors in each of the 3rd and 6th horizontal rows and also of the 2 parts having 6 conductors in each of the 1st and the 4th horizontal rows.

For parallel connection of the 2 groups with 3 parts each, connect $A1_1$ with $A3_4$, and $A1_3$ with $A3_2$.

$A1_1$, $B1_1$, and $C1_3$ can be used as phase beginnings.

In the second example of Art. 5-4, the 18-pole winding in 114 slots treated here as a wave winding has been laid out as an unbalanced lap winding. A comparison of the slots assigned to the 3 phases shows that both windings have the same unbalance.

8-8. Layout of a Winding with a Number of Slots Not Divisible by 3. Since the winding pitch and the magnitude of D in the D-series depend upon the value of spp in all fractional-slot wave windings, the general features of the unbalanced wave windings, with the number of slots not divisible by 3, are the same as those of the unbalanced wave windings with the number of slots divisible by 3. Thus, corresponding to Table 8-24 and Arts. 8-4 to 8-7,

$d = 3 \quad a = 0 \quad$ winding pitch $= 2N$

$d = 6 \quad a = 0 \quad$ winding pitch $= N$

$d = 9 \quad a = +3 \quad$ winding pitch $= D$

$d = 9 \quad a = -3 \quad$ winding pitch $= N - D$

and this means that the connection chart (winding-pitch series) is to be determined from the D-series in the same manner as in Arts. 8-5 to 8-7. Due to the fact that the number of slots is not divisible by 3, the distribution of the coils among the 3 phases is different from that given in Arts. 8-5 to 8-7 for unbalanced windings with a number of slots divisible by 3. Therefore, the formulae for the starts and ends of the parts given there do not apply here.

As in the case when S is divisible by 3, the winding is to be wound in coil series with abnormal-front pitches when a = 0 (see Arts. 8-5 and 8-6); the winding has no abnormal-front pitches when a is different from 0. There are 2 parts in each phase, independent of the number of poles, when a = 0; there are $\left[\frac{\text{(No. of poles)}}{d} \times a\right]$ parts in each phase when a is not equal to 0.

The corresponding numbers of poles, slots, and spp are given in Table 5-4. Some coils must be left out in order to make the number of coils the same for all 3 phases. The magnitude of the unbalance and the possibility of parallel circuits depend upon the location of the slots from which coils are omitted. (see Art. 5-5). For this reason, the unbalanced windings in which the number of slots is not divisible by 3 must be treated individually.

This will be explained by an example of an 8-pole winding in 64 slots. Table 5-4 yields for 8 poles and 64 slots spp = 2 2/3 = $\frac{8}{3}$. Thus, N = 8, d = 3, and n = 2. Table 8-24 shows that for $\frac{n}{d}$ = 2/3, $\frac{(6n + a)}{d}$ = 4, and a = 0. The winding pitch is then 6 x 2 + 4 = 16 = 2N, the back pitch = front pitch = 8. From Eq. 8-2

$$D = \frac{3 \times 8 \times P + 3}{3} = 1 \qquad P = 0$$

Applying rule (c) of Art. 8-4, the following D-series is obtained (see also Art. 7-5):

	A			C		B	
1	2	3	4	5	6	7	8
9	10	11	12	13	⑭	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56
57	58	59	60	61	62	63	64

D-series

There are $\frac{S}{N} = \frac{64}{8} = 8$ horizontal rows with N = 8 numbers in each row. The numbers of any horizontal row are obtained by adding N = 8 to the numbers of the foregoing horizontal row.

Since winding pitch = 2N, the numbers which follow the winding pitch series

1, 1 + (winding pitch), 1 + 2 x (winding pitch) ...

will be found as alternate numbers of the vertical rows.

In order to lay out the winding, connect upper conductor 1 with lower conductor 1 + 8 = 9, and this latter conductor with upper conductor 9 + 8 = 17 which is the third conductor in the first column. Now connect 17 with lower conductor 17 + 8 = 25, finishing the second coil. Further, connect lower conductor 25 with upper conductor 25 + 8 = 33 which is the fifth conductor of the first column, and so forth. As in the case $\frac{S}{3}$ = integer (Art. 8-5), $\frac{S}{2N} = \frac{64}{16} = 4$ coils constitute a coil series. After 4 coils have been accomplished, increase the front pitch by 1 and connect the last lower conductor of the first coil series, i.e., conductor 49 + 8 = 57, with upper conductor 2 which starts the second coil series. Wind continuously until the first part of phase A is accomplished.

Since S = 64, 3 winding parts will be made with 11 coils each and 3 with 10 coils each. One coil will be left out. Thus, the first part of phase A will be accomplished after 11 coils have been connected. This contains the coils with the upper conductors 1, 17, 33, 49, 2, 18, 34, 50, 3, 19, and 35. The first part of phase A ends with the lower conductor 35 + 8 = 43. One front pitch ahead of this latter conductor, i.e., with upper conductor 43 + 8 = 51, the first part of phase C starts and it is to be wound continuously in the same manner as the first part of phase A. The first part of phase B with 10 coils follows after the first part of phase C with 10 coils. Then the second parts of phases A, C, and B with 10, 11, and 11 coils respectively, follow. The connection chart (winding-pitch series) for all 3 phases is then

Al_1	1	17	33	49	2	18	34	50	3	19	35	
Al_3	9	25	41	57	10	26	42	58	11	27		
Cl_1	51	4	20	36	52	5	21	37	53	6	22	y-series
Cl_3	43	59	12	28	44	60	13	29	45	61	⑭	
Bl_1	38	54	7	23	39	55	8	24	40	56		
Bl_3	30	46	62	15	31	47	63	16	32	48	64	

Upper conductor 14 and the corresponding lower conductor 14 + 8 = 22 are left out. There are 13 long-front pitches before the upper conductors 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15, and 16. The distribution of the coils among the 3 phases is indicated in the D-series by broken lines.

The error in the angle is $-2^{\circ}\,9'$ for phase C and $-1^{\circ}\,6'$ for phase B. The error in magnitude is 1%. The omitted coil is the last coil of the second wave of phase C. If coil 3 is left out and the distribution among the phases made as shown below:

1	2	③	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56
57	58	59	60	61	62	63	64

D-series

the connection chart (winding-pitch series) becomes:

Al_1	1	17	33	49	2	18	34	50	③	19	35
Al_3	9	25	41	57	10	26	42	58	11	27	43
Cl_1	51	4	20	36	52	5	21	37	53	6	22
Cl_3	59	12	28	44	60	13	29	45	61	14	
Bl_1	38	54	7	23	39	55	8	24	40	56	
Bl_3	30	46	62	15	31	47	63	16	32	48	64

y-series

The omitted coil, 3, lies in the first wave of phase A and is not the last coil of the wave. The error in the angle is now $+1^{\circ}\,5'$ for phase C and $-1^{\circ}\,4'$ for phase B. The error in magnitude is 0.5%.

Parallel connection of the 2 parts of each phase is not possible because they have different numbers of coils. For series connection note that Al_1 and Al_3 (Cl_1 and Cl_3, Bl_1 and Bl_3) have opposite polarities. Thus, for series connection, connect Al_2 with Al_4, Cl_2 with Cl_4, and Bl_2 with Bl_4. Al_1, Al_3, Cl_1, Cl_3, Bl_1, and Bl_3 are the leads.

Al_1, Bl_1, and Cl_3 are to be used as phase beginnings, i.e., these 3 leads are to be connected to slip rings or to the line.

8-9. Magnitude of Unbalance. The same unbalance in the magnitude of the electromotive or magnetomotive forces as well as in the angles between them can be expected as for the unbalanced lap winding (Art. 5-7) if the distribution of the slots among the phases is made in the same manner as for the unbalanced lap windings. The examples treated in the foregoing articles show that this is possible. The calculation of the magnitude of unbalance is explained in Appendix 4.

TABLE 8-1

Connection Table for 42 Slots, 6 Poles, spp=2 1/3; $(y=14;\ y_b=7;\ y_f=7;\ a=o;\ d=3)$

REFERENCE WORKING DIAGRAM Fig. 8-1

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	7	↑	A_1 = 1	A_2 = 10	↓	↑	B_1 = 33	B_2 = 42	↓	↑	C_1 = 17	C_2 = 26	↓
	7	↓	A_3 = 8	A_4 = 17	↑	↓	B_3 = 40	B_4 = 7	↑	↓	C_3 = 24	C_4 = 33	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$		$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

Long-front pitches lie before upper conductors 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, and 14.

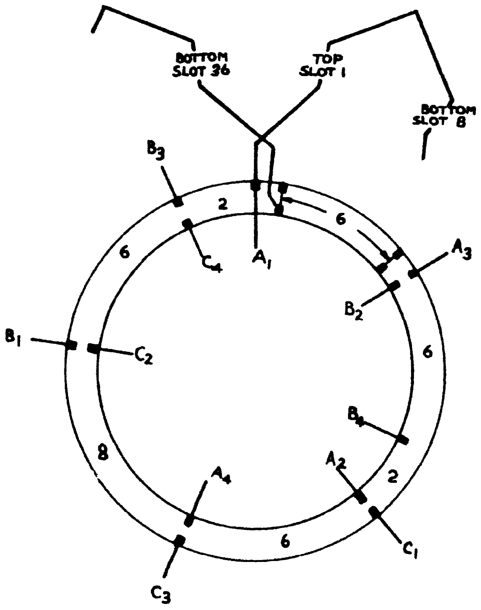


Fig. 8-1. Working Diagram for 42 slots, 6 poles, spp = 2 1/3

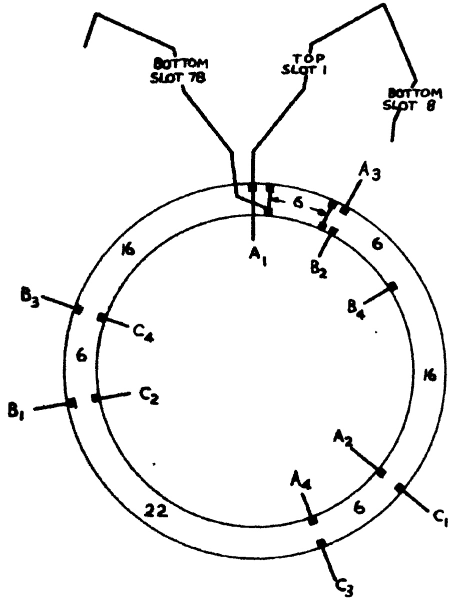


Fig. 8-2. Working Diagram for 84 slots, 12 poles, spp = 2 1/3

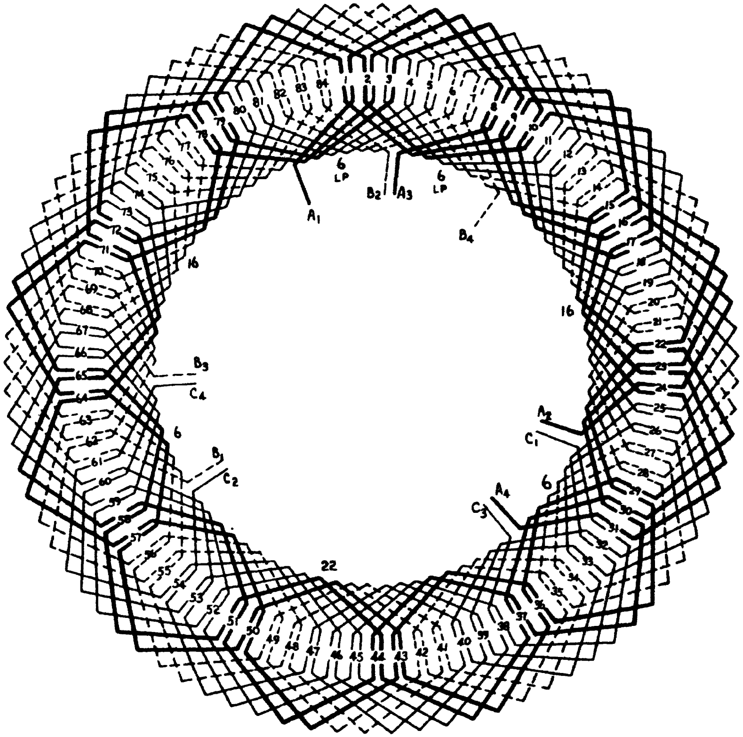


Fig. 8-2a. Fully developed Winding Diagram for 84 slots, 12 poles, spp = 2 1/3

TABLE 8-2

Connection Table for 84 Slots, 12 Poles, spp=2 1/3; $(y=14;\ y_b=7;\ y_f=7;\ a=o;\ d=3)$

REFERENCE WORKING DIAGRAM Fig. 8-2

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	14	↑	$A_1 = 1$	$A_2 = 24$	↓	↑	$B_1 = 61$	$B_2 = 84$	↓	↑	$C_1 = 31$	$C_2 = 54$	↓
	14	↓	$A_3 = 8$	$A_4 = 31$	↑	↓	$B_3 = 68$	$B_4 = 7$	↑	↓	$C_3 = 38$	$C_4 = 61$	↑

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

Long-front pitches lie before upper conductors 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, and 14.

TABLE 8-3

Connection Table for 126 Slots, 18 Poles, spp=2 1/3; $(y=14;\ y_b=7;\ y_f=7;\ a=o;\ d=3)$

REFERENCE WORKING DIAGRAM Fig. 8-3

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	21	↑	$A_1 = 1$	$A_2 = 38$	↓	↑	$B_1 = 89$	$B_2 = 126$	↓	↑	$C_1 = 45$	$C_2 = 82$	↓
	21	↓	$A_3 = 8$	$A_4 = 45$	↑	↓	$B_3 = 96$	$B_4 = 7$	↑	↓	$C_3 = 52$	$C_4 = 89$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

Long-front pitches lie before upper conductors 2, 3, 4, 5, 6, 7, 9, 10, 11, 12, 13, and 14.

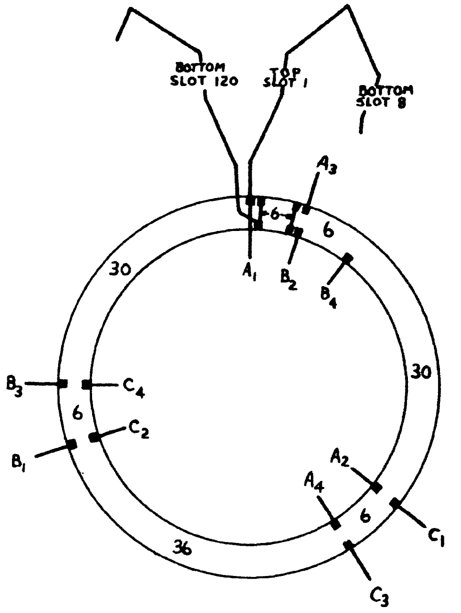


Fig. 8-3. Working Diagram for 126 slots, 18 poles, spp = 2 1/3

TABLE 8-4

Connection Table for 120 Slots, 12 Poles, spp=3 1/3; ($y=20$; $y_b=10$; $y_f=10$; $a=0$; $d=3$)

REFERENCE WORKING DIAGRAM Fig. 8-4

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	20	↑	A_1 = 1	A_2 = 34	↓	↑	B_1 = 87	B_2 = 120	↓	↑	C_1 = 44	C_2 = 77	↓
	20	↓	A_3 = 11	A_4 = 44	↑	↓	B_3 = 97	B_4 = 10	↑	↓	C_3 = 54	C_4 = 87	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

Long-front pitches lie before upper conductors. 2, 3, 4, 5, 6, 7, 8. 9, 10, 12, 13, 14, 15, 16, 17, 18, 19, and 20.

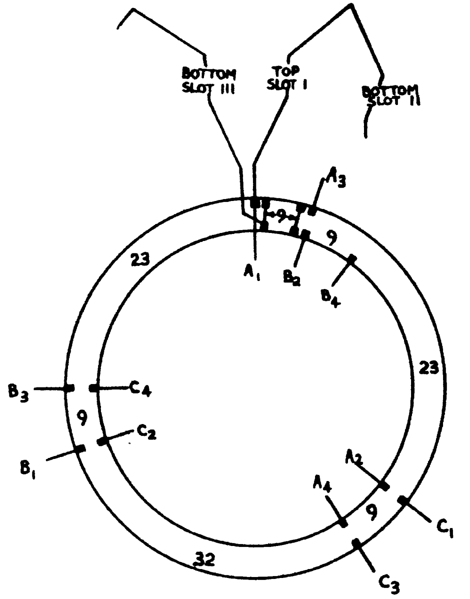


Fig. 8-4. Working Diagram for 120 slots, 12 poles, spp = 3 1/3

TABLE 8-5

Connection Table for 240 Slots, 24 Poles, spp=3 1/3; (y=20; y_b=10; y_f=10; a=0; d=3)

REFERENCE WORKING DIAGRAM Fig. 8-5

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	40	↑	A_1 = 1	A_2 = 74	↓	↑	B_1 = 167	B_2 = 240	↓	↑	C_1 = 84	C_2 = 157	↓
	40	↓	A_3 = 11	A_4 = 84	↑	↓	B_3 = 177	B_4 = 10	↑	↓	C_3 = 94	C_4 = 167	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

Long-front pitches lie before upper conductors 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 18, 19, and 20.

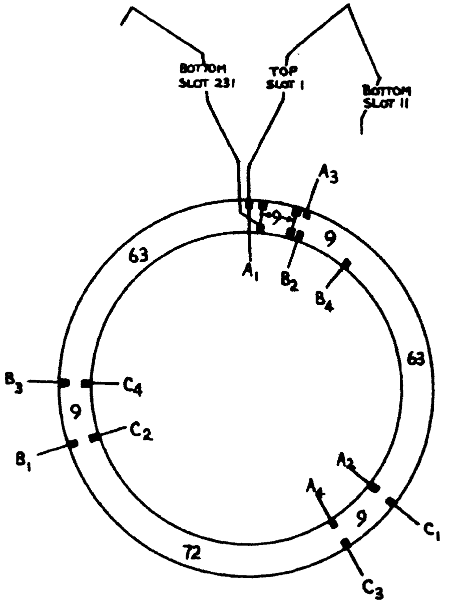


Fig. 8-5. Working Diagram for 240 slots, 24 poles, spp = 3 1/3

TABLE 8-6

Connection Table for 96 Slots, 6 Poles, spp=5 1/3; (y=32; y_b=16; y_f=16; a=0; d=3)

REFERENCE WORKING DIAGRAM Fig. 8-6

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	16	↑	A_1 = 1	A_2 = 22	↓	↑	B_1 = 75	B_2 = 96	↓	↑	C_1 = 38	C_2 = 59	↓
	16	↓	A_3 = 17	A_4 = 38	↑	↓	B_3 = 91	B_4 = 16	↑	↓	C_3 = 54	C_4 = 75	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	DELTA CONNECTION
1	A[illegible]	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

Long-front pitches lie before upper conductors 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, and 32.

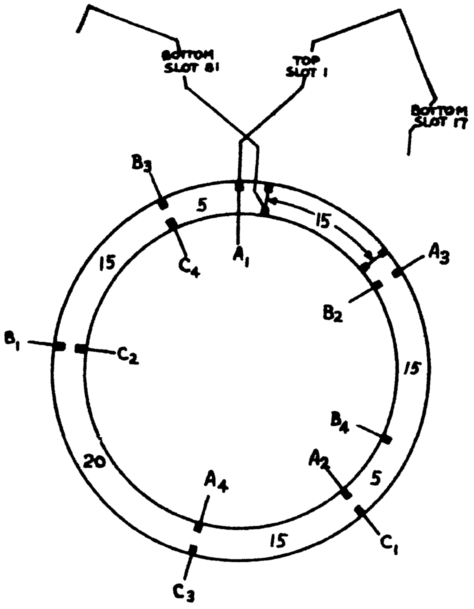


Fig. 8-6. Working Diagram for 96 slots, 6 poles, spp = 5 1/3

TABLE 8-7

Connection Table for 192 Slots, 12 Poles, spp=5 1/3; $(y=32;\ y_b=16;\ y_f=16;\ a=0;\ d=3)$

REFERENCE WORKING DIAGRAM Fig. 8-7

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	32	↑	$A_1 = 1$	$A_2 = 54$	↓	↑	$B_1 = 139$	$B_2 = 192$	↓	↑	$C_1 = 70$	$C_2 = 123$	↓
	32	↓	$A_3 = 17$	$A_4 = 70$	↑	↓	$B_3 = 155$	$B_4 = 16$	↑	↓	$C_3 = 86$	$C_4 = 139$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

Long-front pitches lie before upper conductors 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, and 32.

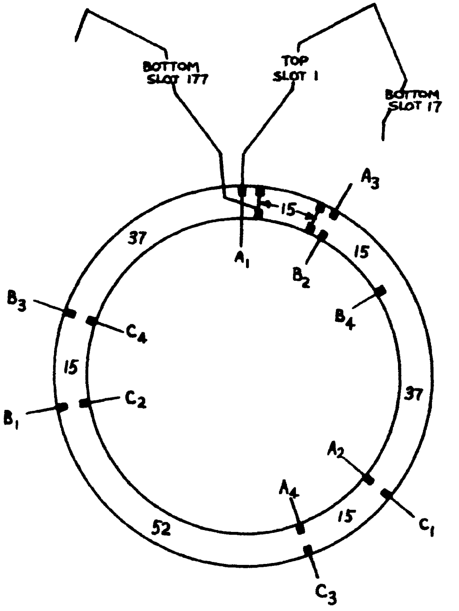


Fig. 8-7. Working Diagram for 192 slots, 12 poles, spp = 5 1/3

TABLE 8-8

Connection Table for 48 Slots, 6 Poles, spp=2 2/3; ($y=16$; $y_b=8$; $y_f=8$; $a=0$; $d=3$)

REFERENCE WORKING DIAGRAM Fig. 8-8

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	8	↑	$A_1 = 1$	$A_2 = 27$	↓	↑	$B_1 = 22$	$B_2 = 48$	↓	↑	$C_1 = 35$	$C_2 = 14$	↓
	8	↓	$A_3 = 9$	$A_4 = 35$	↑	↓	$B_3 = 30$	$B_4 = 8$	↑	↓	$C_3 = 43$	$C_4 = 22$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

Long-front pitches lie before upper conductors 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, and 16.

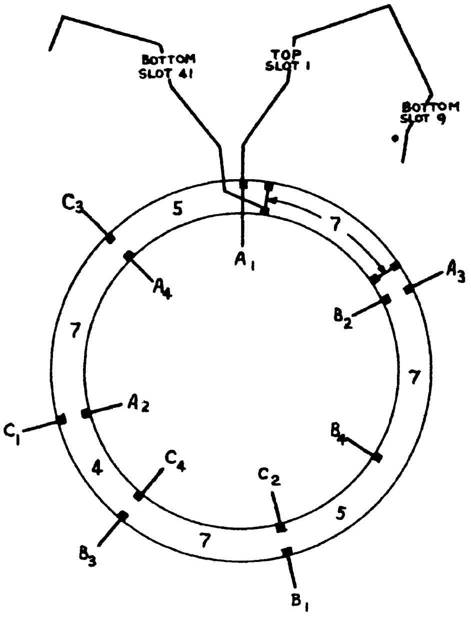


Fig. 8-8. Working Diagram for 48 slots, 6 poles, spp = 2 2/3

TABLE 8-9

Connection Table for 96 Slots, 12 Poles, spp=2 2/3;($y=16$; $y_b=8$; $y_f=8$; a=0; d=3)

REFERENCE WORKING DIAGRAM Fig. 8-9

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	16	↑	A_1 = 1	A_2 = 59	↓	↑	B_1 = 38	B_2 = 96	↓	↑	C_1 = 67	C_2 = 30	↓
	16	↓	A_3 = 9	A_4 = 67	↑	↓	B_3 = 46	B_4 = 8	↑	↓	C_3 = 75	C_4 = 38	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

Long-front pitches lie before upper conductors 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, and 16.

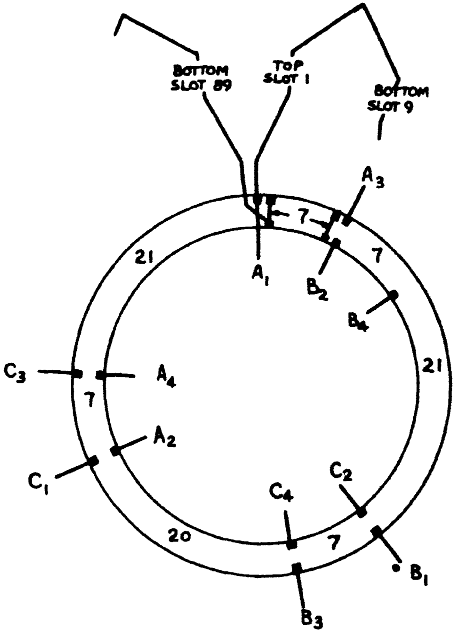


Fig. 8-9. Working Diagram for 96 slots, 12 poles, spp = 2 2/3

TABLE 8-10

Connection Table for 144 Slots, 18 Poles, spp=2 2/3; (y=16; y_b=8; y_f=8; a=0; d=3)

REFERENCE WORKING DIAGRAM Fig. 8-10

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	24	↑	A_1 = 1	A_2 = 91	↓	↑	B_1 = 54	B_2 = 144	↓	↑	C_1 = 99	C_2 = 46	↓
	24	↓	A_3 = 9	A_4 = 99	↑	↓	B_3 = 62	B_4 = 8	↑	↓	C_3 = 107	C_4 = 54	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connections
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

Long-front pitches lie before upper conductors 2, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 15, and 16.

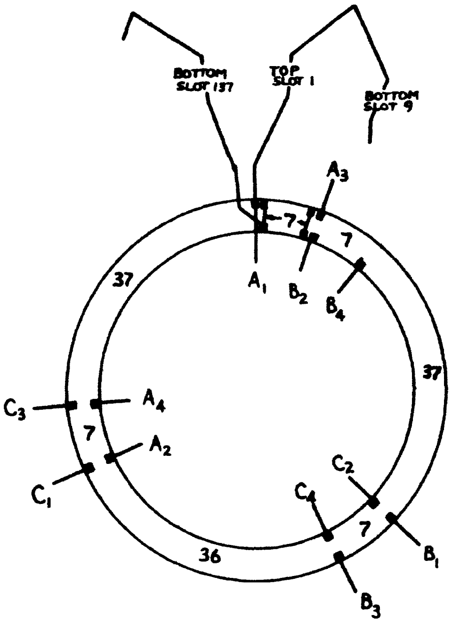


Fig. 8-10. Working Diagram for 144 slots, 18 poles, spp = 2 2/3

TABLE 8-11

Connection Table for 66 Slots, 12 Poles, spp=1 5/6;($y=11$; $y_b=5$; $y_f=6$; $a=0$; $d=6$)

REFERENCE WORKING DIAGRAM Fig. 8-11

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	12	↑	$A_1 = 1$	$A_2 = 62$	↓	↑	$B_1 = 5$	$B_2 = 66$	↓	↑	$C_1 = 3$	$C_2 = 64$	↓
	10	↓	$A_3 = 7$	$A_4 = 46$	↑	↓	$B_3 = 32$	$B_4 = 5$	↑	↓	$C_3 = 52$	$C_4 = 26$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$

Long-front pitches lie before upper conductors 2, 4, 6, 8, 9, 10, and 11.

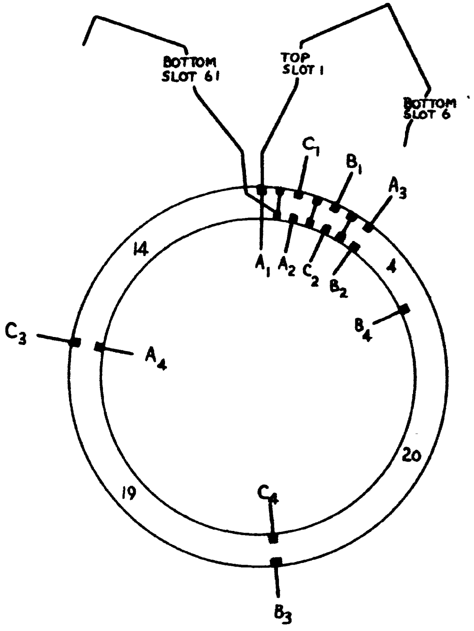


Fig. 8-11. Working Diagram for 66 slots, 12 poles, spp = 1 5/6

TABLE 8-12

Connection Table for 99 Slots, 18 Poles, spp=1 5/6; $\left(y=11;\ y_b=5;\ y_f=6;\ a=0;\ d=6\right)$

REFERENCE WORKING DIAGRAM Fig. 8-12

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	18	↑	A_1 = 1	A_2 = 95	↓	↑	B_1 = 5	B_2 = 99	↓	↑	C_1 = 3	C_2 = 97	↓
	15	↓	A_3 = 7	A_4 = 68	↑	↓	B_3 = 43	B_4 = 5	↑	↓	C_3 = 74	C_4 = 37	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$

Long-front pitches lie before upper conductors 2, 4, 6, 8, 9, 10, and 11.

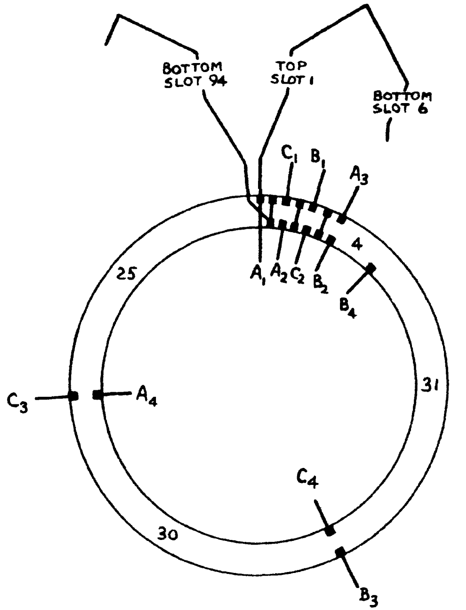


Fig. 8-12. Working Diagram for 99 slots, 18 poles, spp = 1 5/6

TABLE 8-13

Connection Table for 78 Slots, 12 Poles, spp=2 1/6; $(y=13;\ y_b=6;\ y_f=7;\ a=0;\ d=6)$

REFERENCE WORKING DIAGRAM Fig. 8-13

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	12	↑	$A_1 = 1$	$A_2 = 73$	↓	↑	$B_1 = 5$	$B_2 = 77$	↓	↑	$C_1 = 3$	$C_2 = 75$	↓
	14	↓	$A_3 = 7$	$A_4 = 28$	↑	↓	$B_3 = 63$	$B_4 = 6$	↑	↓	$C_3 = 35$	$C_4 = 56$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$

Long-front pitches lie before upper conductors 2, 4, 6, 8, 10, 11, 12, and 13.

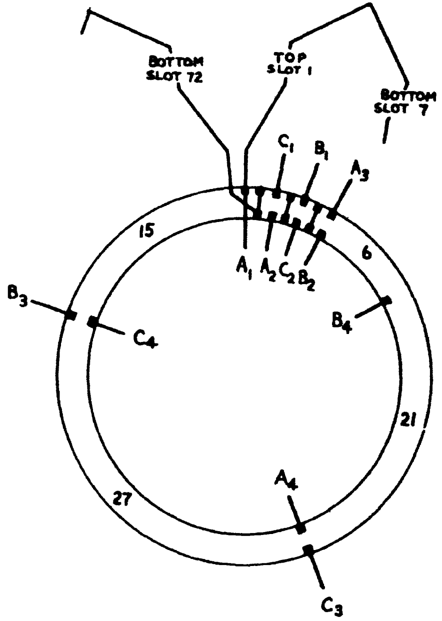


Fig. 8-13. Working Diagram for 78 slots, 12 poles, spp = 2 1/6

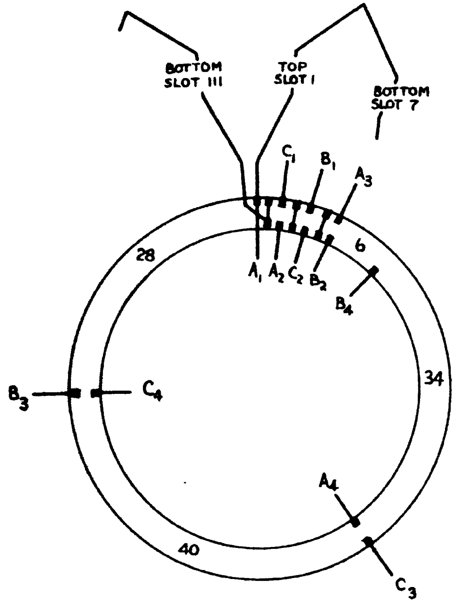


Fig. 8-14. Working Diagram for 117 slots, 18 poles, spp = 2 1/6

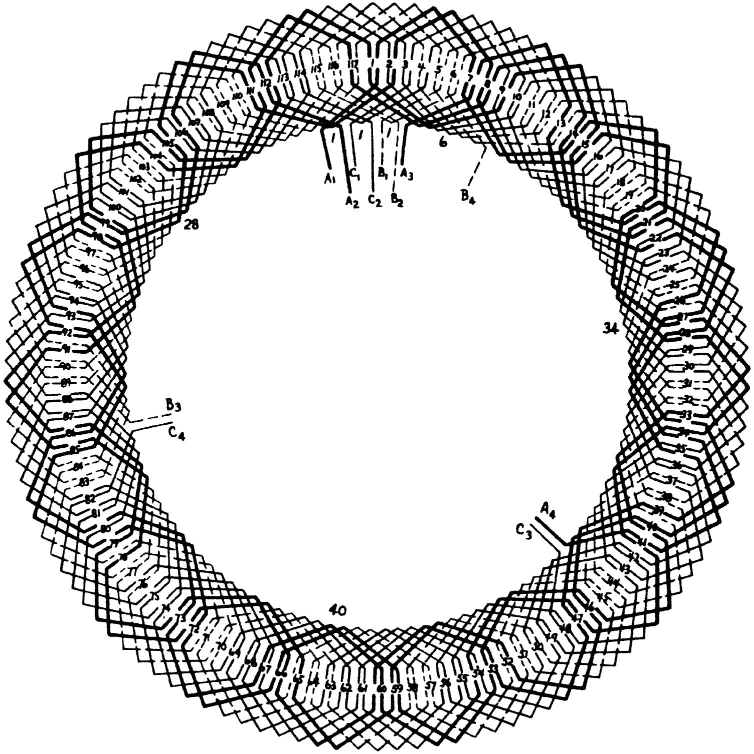


Fig. 8-14a. Fully developed Winding Diagram for 117 slots, 18 poles, spp = 2 1/6

TABLE 8-14

Connection Table for 117 Slots, 18 Poles, spp=2 1/6; $(y=13;\ y_b=6;\ y_f=7;\ a=0;\ d=6)$

REFERENCE WORKING DIAGRAM Fig. 8-14

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	18	↑	A_1 = 1	A_2 = 112	↓	↑	B_1 = 5	B_2 = 116	↓	↑	C_1 = 3	C_2 = 114	↓
	21	↓	A_3 = 7	A_4 = 41	↑	↓	B_3 = 89	B_4 = 6	↑	↓	C_3 = 48	C_4 = 82	↑

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$

Long-front pitches lie before upper conductors 2, 4, 6, 8, 10, 11, 12, and 13.

TABLE 8-15

Connection Table for 102 Slots, 12 Poles, spp=2 5/6; ($y=17$; $y_b=8$; $y_f=9$; $a=0$; $d=6$)

REFERENCE WORKING DIAGRAM Fig. 8-15

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	18	↑	$A_1 = 1$	$A_2 = 96$	↓	↑	$B_1 = 7$	$B_2 = 102$	↓	↑	$C_1 = 4$	$C_2 = 99$	↓
	16	↓	$A_3 = 10$	$A_4 = 71$	↑	↓	$B_3 = 49$	$B_4 = 8$	↑	↓	$C_3 = 80$	$C_4 = 40$	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$

Long-front pitches lie before upper conductors 2, 3, 5, 6, 8, 9, 11, 12,,13, 14, 15, 16, and 17.

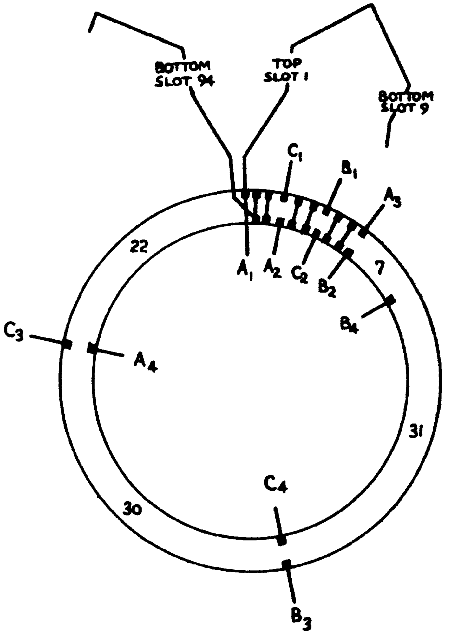


Fig. 8-15. Working Diagram for 102 slots, 12 poles, spp = 2 5/6

TABLE 8-16

Connection Table for 153 Slots, 18 Poles, spp=2 5/6; (y=17; y_b=8; y_f=9; a=0; d=6)

REFERENCE WORKING DIAGRAM Fig. 8-16

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	26	↑	A_1 = 1	A_2 = 147	↓	↑	B_1 = 7	B_2 = 153	↓	↑	C_1 = 4	C_2 = 150	↓
	25	↓	A_3 = 10	A_4 = 105	↑	↓	B_3 = 66	B_4 = 8	↑	↓	C_3 = 114	C_4 = 57	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$

Long-front pitches lie before upper conductors 2, 3, 5, 6, 8, 9, 11, 12, 13, 14, 15, 16, and 17.

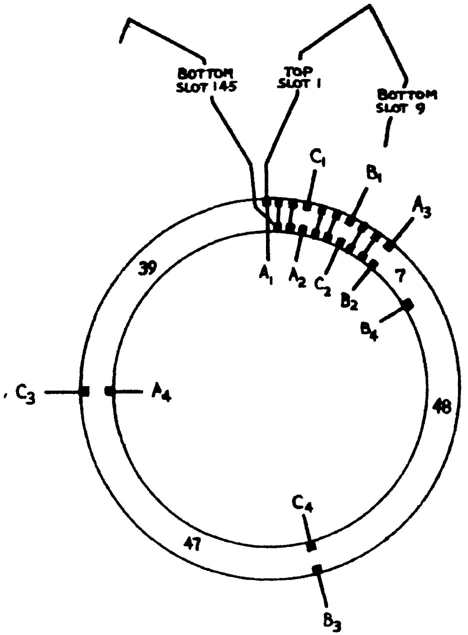


Fig. 8-16. Working Diagram for 153 slots, 18 poles, spp = 2 5/6

TABLE 8-17

Connection Table for 105 Slots, 6 Poles, spp=5 5/6; (y=35; y_b=17; y_f=18; a=0; d=6)

REFERENCE WORKING DIAGRAM Fig. 8-17

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity	Polarity	Starts	Ends	Polarity
2	18	↑	A_1 = 1	A_2 = 93	↓	↑	B_1 = 13	B_2 = 105	↓	↑	C_1 = 7	C_2 = 99	↓
	17	↓	A_3 = 19	A_4 = 76	↑	↓	B_3 = 65	B_4 = 17	↑	↓	C_3 = 94	C_4 = 47	↑

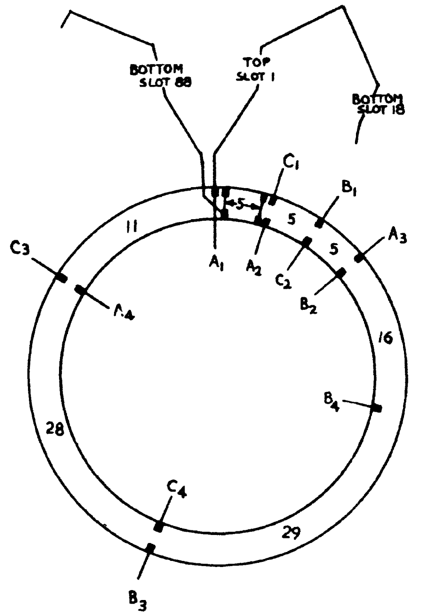


Fig. 8-17. Working Diagram for 105 slots, 6 poles, spp = 5 5/6

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$

Long-front pitches lie before upper conductors 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, and 35.

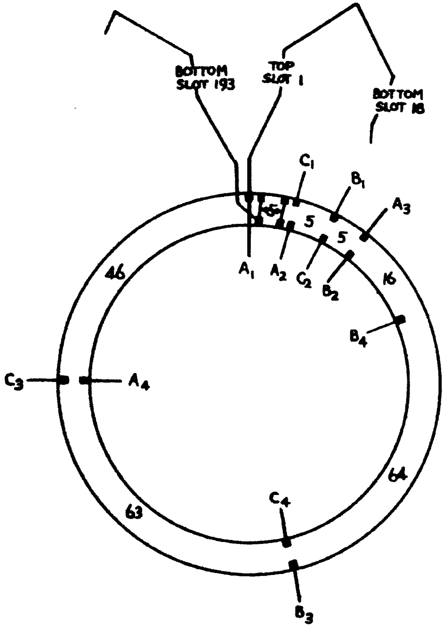


Fig. 8-18. Working Diagram for 210 slots, 12 poles, spp = 5 5/6

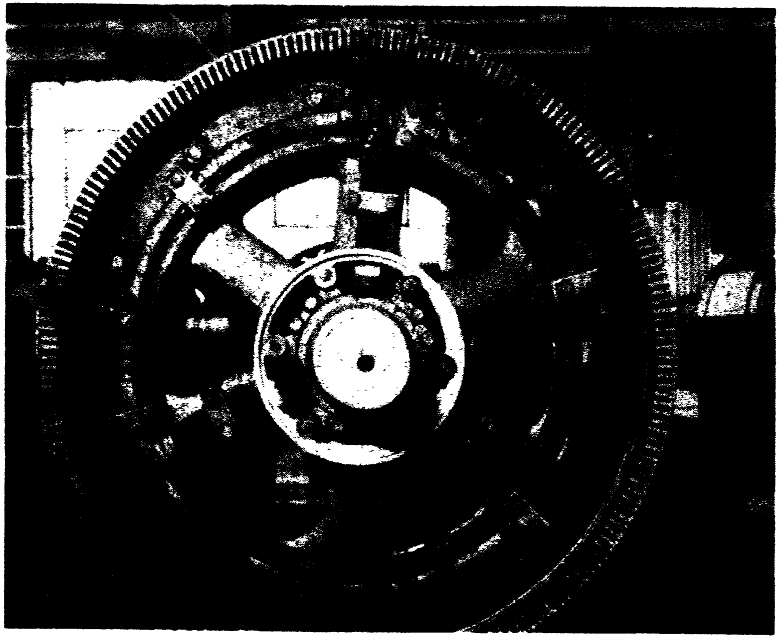


Fig. 8-18a. Photograph of the lead or connection end of a 12-pole wave wound rotor with 210 slots, spp = 5 5/6. Fig. 8-18 is the Working Diagram of this winding. Connection Table 8-18 was used to connect the winding parts 1 delta.

TABLE 8-18

Connection Table for 210 Slots, 12 Poles, spp=5 5/6; $\left(y=35;\ y_b=17;\ y_f=18;\ a=0;\ d=6\right)$

REFERENCE WORKING DIAGRAM Fig. 8-18

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				PHASE B				PHASE C			
		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS		TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity	Polar-ity	Starts	Ends	Polar-ity
2	35	↑	A_1 = 1	A_2 = 198	↓	↑	B_1 = 13	B_2 = 210	↓	↑	C_1 = 7	C_2 = 204	↓
	35	↓	A_3 = 19	A_4 = 146	↑	↓	B_3 = 100	B_4 = 17	↑	↓	C_3 = 164	C_4 = 82	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	A_1	$A_2 \rightarrow A_4$	A_3	$A_3 \rightarrow B_1$
	B_1	$B_2 \rightarrow B_4$	B_3	$B_3 \rightarrow C_3$
	C_3	$C_2 \rightarrow C_4$	C_1	$C_1 \rightarrow A_1$
2	$A_1 \rightarrow A_4$	-	$A_2 \rightarrow A_3$	$A_2 \rightarrow A_3 \rightarrow B_1 \rightarrow B_4$
	$B_1 \rightarrow B_4$	-	$B_2 \rightarrow B_3$	$B_2 \rightarrow B_3 \rightarrow C_2 \rightarrow C_3$
	$C_2 \rightarrow C_3$	-	$C_1 \rightarrow C_4$	$C_1 \rightarrow C_4 \rightarrow A_1 \rightarrow A_4$

Long-front pitches lie before upper conductors 2, 3, 4, 5, 6, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, and 35.

TABLE 8-19

Connection Table for 96 Slots, 18 Poles, spp=1 7/9; $(y=11;\ y_b=5;\ y_f=6;\ a=+3;\ d=9)$

REFERENCE WORKING DIAGRAM Fig. 8-19

No. of Parts Per Phase	No. of Coils Per Part	PHASE A				No. of Coils per Part	PHASE B				No. of Coils per Part	PHASE C			
		TOP LEADS		BOTTOM LEADS			TOP LEADS		BOTTOM LEADS			TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity		Polarity	Starts	Ends	Polarity		Polarity	Starts	Ends	Polarity
6	6	↑	$A1_1$ = 1	$A1_2$ = 61	↓	5	↑	$B1_1$ = 26	$B1_2$ = 75	↓	5	↑	$C1_1$ = 67	$C1_2$ = 20	↓
	5	↓	$A2_1$ = 17	$A2_2$ = 66	↑	5	↓	$B2_1$ = 42	$B2_2$ = 91	↑	6	↓	$C2_1$ = 72	$C2_2$ = 36	↑
	5	↑	$A3_1$ = 33	$A3_2$ = 82	↓	6	↑	$B3_1$ = 47	$B3_2$ = 11	↓	5	↑	$C3_1$ = 88	$C3_2$ = 41	↓
	6	↓	$A1_3$ = 49	$A1_4$ = 13	↑	5	↓	$B1_3$ = 74	$B1_4$ = 27	↑	5	↓	$C1_3$ = 19	$C1_4$ = 68	↑
	5	↑	$A2_3$ = 65	$A2_4$ = 18	↓	5	↑	$B2_3$ = 90	$B2_4$ = 43	↓	6	↑	$C2_3$ = 24	$C2_4$ = 84	↓
	5	↓	$A3_3$ = 81	$A3_4$ = 34	↑	6	↓	$B3_3$ = 95	$B3_4$ = 59	↑	5	↓	$C3_3$ = 40	$C3_4$ = 89	↑

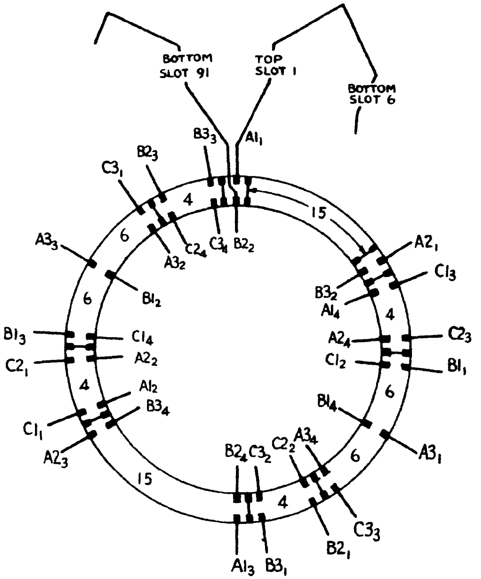


Fig. 8-19. Working Diagram for 96 slots, 18 poles, spp = 1 7/9

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A3_1$ $A3_2 \rightarrow A3_4$ $A3_3 \rightarrow A2_3$ $A2_4 \rightarrow A1_4$	$A1_3$	$A1_3 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B3_1$ $B3_2 \rightarrow B3_4$ $B3_3 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$	$B1_3$	$B1_3 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C3_1$ $C3_2 \rightarrow C3_4$ $C3_3 \rightarrow C2_3$ $C2_4 \rightarrow C1_4$	$C1_1$	$C1_1 \rightarrow A1_1$
2	$A1_1 \rightarrow A3_4$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A3_1$ $A3_3 \rightarrow A2_3$ $A2_4 \rightarrow A1_4$	$A1_3 \rightarrow A3_2$	$A1_3 \rightarrow A3_2 \rightarrow B1_1 \rightarrow B3_4$
	$B1_1 \rightarrow B3_4$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B3_1$ $B3_3 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$	$B1_3 \rightarrow B3_2$	$B1_3 \rightarrow B3_2 \rightarrow C1_3 \rightarrow C3_2$
	$C1_3 \rightarrow C3_2$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C3_1$ $C3_2 \rightarrow C3_4$ $C3_3 \rightarrow C2_3$	$C1_1 \rightarrow C3_4$	$C1_1 \rightarrow C3_4 \rightarrow A1_1 \rightarrow A3_4$

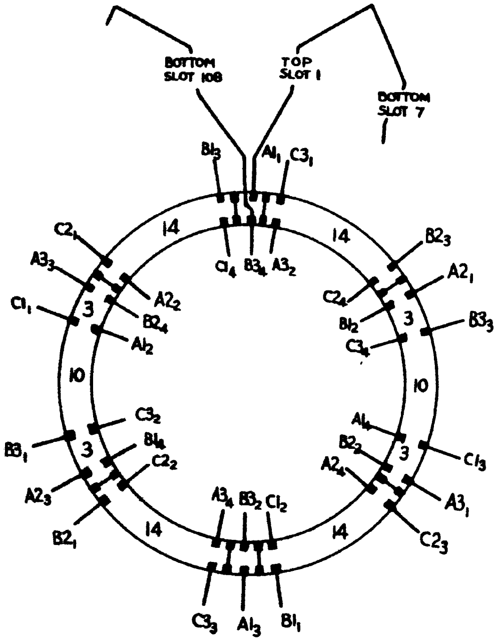


Fig. 8-20. Working Diagram for 114 slots, 18 poles, spp = 2 1/9

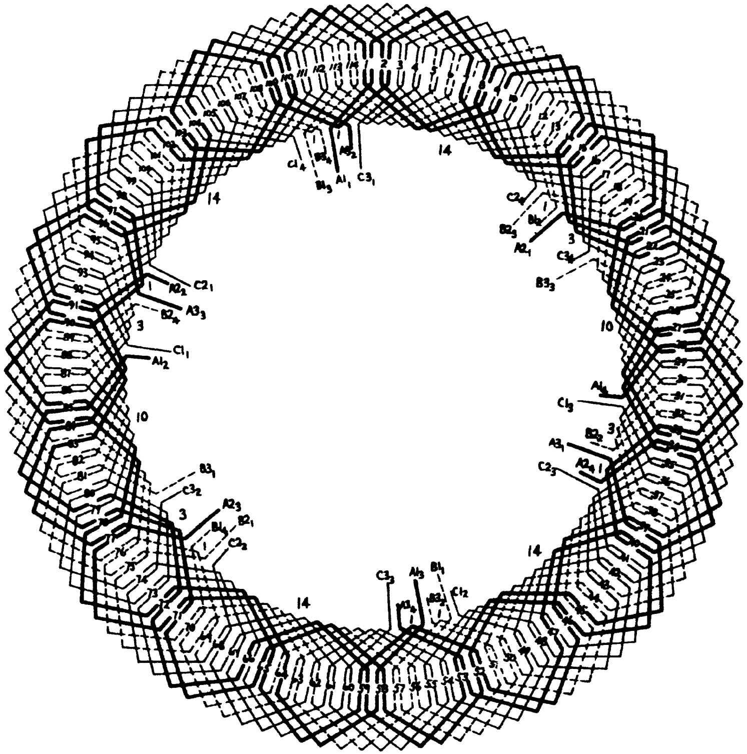


Fig. 8-20a. Fully developed Winding Diagram for 114 slots, 18 poles, spp = 2 1/9

TABLE 8-20

Connection Table for 114 Slots, 18 Poles, spp=2 1/9; (y=13; y_b=6; y_f=7; a=+3; d=9)

REFERENCE WORKING DIAGRAM Fig. 8-20

No. of Parts per Phase	No. of Coils per Part	PHASE A				No. of Coils per Part	PHASE B				No. of Coils per Part	PHASE C			
		TOP LEADS		BOTTOM LEADS			TOP LEADS		BOTTOM LEADS			TOP LEADS		BOTTOM LEADS	
		Polar-ity	Starts	Ends	Polar-ity		Polar-ity	Starts	Ends	Polar-ity		Polar-ity	Starts	Ends	Polar-ity
6	7	↑	$A1_1$ = 1	$A1_2$ = 85	↓	6	↑	$B1_1$ = 56	$B1_2$ = 13	↓	6	↑	$C1_1$ = 92	$C1_2$ = 49	↓
	6	↓	$A2_1$ = 20	$A2_2$ = 91	↑	6	↓	$B2_1$ = 75	$B2_2$ = 32	↑	7	↓	$C2_1$ = 98	$C2_2$ = 68	↑
	6	↑	$A3_1$ = 39	$A3_2$ = 110	↓	7	↑	$B3_1$ = 81	$B3_2$ = 51	↓	6	↑	$C3_1$ = 3	$C3_2$ = 74	↓
	7	↓	$A1_3$ = 58	$A1_4$ = 28	↑	6	↓	$B1_3$ = 113	$B1_4$ = 70	↑	6	↓	$C1_3$ = 35	$C1_4$ = 106	↑
	6	↑	$A2_3$ = 77	$A2_4$ = 34	↓	6	↑	$B2_3$ = 18	$B2_4$ = 89	↓	7	↑	$C2_3$ = 41	$C2_4$ = 11	↓
	6	↓	$A3_3$ = 96	$A3_4$ = 53	↑	7	↓	$B3_3$ = 24	$B3_4$ = 108	↑	6	↓	$C3_3$ = 60	$C3_4$ = 17	↑

CONNECTION OF PARTS

No. of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \to A2_2$ $A2_1 \to A3_1$ $A3_2 \to A3_4$ $A3_3 \to A2_3$ $A2_4 \to A1_4$	$A1_3$	$A1_3 \to B1_1$
	$B1_1$	$B1_2 \to B2_2$ $B2_1 \to B3_1$ $B3_2 \to B3_4$ $B3_3 \to B2_3$ $B2_4 \to B1_4$	$B1_3$	$B1_3 \to C1_3$
	$C1_3$	$C1_2 \to C2_2$ $C2_1 \to C3_1$ $C3_2 \to C3_4$ $C3_2 \to C2_3$ $C2_4 \to C1_4$	$C1_1$	$C1_1 \to A1_1$
2	$A1_1 \to A3_4$	$A1_2 \to A2_2$ $A2_1 \to A3_1$ $A3_3 \to A2_3$ $A2_4 \to A1_4$	$A1_3 \to A3_2$	$A1_3 \to A3_2 \to B1_1 \to B3_4$
	$B1_1 \to B3_4$	$B1_2 \to B2_2$ $B2_1 \to B3_1$ $B3_3 \to B2_3$ $B2_4 \to B1_4$	$B1_3 \to B3_2$	$B1_3 \to B3_2 \to C1_3 \to C3_2$
	$C1_3 \to C3_2$	$C1_2 \to C2_2$ $C2_1 \to C3_1$ $C3_3 \to C2_3$ $C2_4 \to C1_4$	$C1_1 \to C3_4$	$C1_1 \to C3_4 \to A1_1 \to A3_4$

TABLE 8-21

Connection Table for 132 Slots, 18 Poles, spp=2 4/9; ($y=15$; $y_b=7$; $y_f=8$; $a=+3$; $d=9$)

REFERENCE WORKING DIAGRAM Fig. 8-21

No. of Parts per Phase	No. of Coils per Part	PHASE A				No. of Coils per Part	PHASE B				No. of Coils per Part	PHASE C			
		TOP LEADS		BOTTOM LEADS			TOP LEADS		BOTTOM LEADS			TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity		Polarity	Starts	Ends	Polarity		Polarity	Starts	Ends	Polarity
6	8	↑	$A1_1$ = 1	$A1_2$ = 113	↓	7	↑	$B1_1$ = 94	$B1_2$ = 59	↓	7	↑	$C1_1$ = 121	$C1_2$ = 86	↓
	7	↓	$A2_1$ = 23	$A2_2$ = 120	↑	7	↓	$B2_1$ = 116	$B2_2$ = 81	↑	8	↓	$C2_1$ = 128	$C2_2$ = 108	↑
	7	↑	$A3_1$ = 45	$A3_2$ = 10	↓	8	↑	$B3_1$ = 123	$B3_2$ = 103	↓	7	↑	$C3_1$ = 18	$C3_2$ = 115	↓
	8	↓	$A1_3$ = 67	$A1_4$ = 47	↑	7	↓	$B1_3$ = 28	$B1_4$ = 125	↑	7	↓	$C1_3$ = 55	$C1_4$ = 20	↑
	7	↑	$A2_3$ = 89	$A2_4$ = 54	↓	7	↑	$B2_3$ = 50	$B2_4$ = 15	↓	8	↑	$C2_3$ = 62	$C2_4$ = 42	↓
	7	↓	$A3_3$ = 111	$A3_4$ = 76	↑	8	↓	$B3_3$ = 57	$B3_4$ = 37	↑	7	↓	$C3_3$ = 84	$C3_4$ = 49	↑

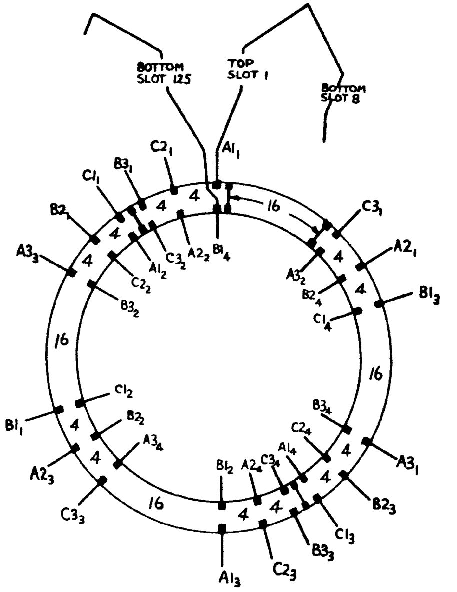


Fig. 8-21. Working Diagram for 132 slots, 18 poles, spp = 2 4/9

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A3_1$ $A3_2 \rightarrow A3_4$ $A3_3 \rightarrow A2_3$ $A2_4 \rightarrow A1_4$	$A1_3$	$A1_3 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B3_1$ $B3_2 \rightarrow B3_4$ $B3_3 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$	$B1_3$	$B1_3 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C3_1$ $C3_2 \rightarrow C3_4$ $C3_3 \rightarrow C2_3$ $C2_4 \rightarrow C1_4$	$C1_1$	$C1_1 \rightarrow A1_1$
2	$A1_1 \rightarrow A3_4$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A3_1$ $A3_3 \rightarrow A2_3$ $A2_4 \rightarrow A1_4$	$A1_3 \rightarrow A3_2$	$A1_3 \rightarrow A3_2 \rightarrow B1_1 \rightarrow B3_4$
	$B1_1 \rightarrow B3_4$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B3_1$ $B3_3 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$	$B1_3 \rightarrow B3_2$	$B1_3 \rightarrow B3_2 \rightarrow C1_3 \rightarrow C3_2$
	$C1_3 \rightarrow C3_2$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C3_1$ $C3_3 \rightarrow C2_3$ $C2_4 \rightarrow C1_4$	$C1_1 \rightarrow C3_4$	$C1_1 \rightarrow C3_4 \rightarrow A1_1 \rightarrow A3_4$

TABLE 8-22

Connection Table for 138 Slots, 18 Poles, spp=2 5/9; ($y=15$; $y_b=7$; $y_f=8$; $a=-3$; $d=9$)

REFERENCE WORKING DIAGRAM Fig. 8-22

No. of Parts per Phase	No. of Coils per Part	PHASE A				No. of Coils per Part	PHASE B				No. of Coils per Part	PHASE C			
		BOTTOM LEADS		TOP LEADS			BOTTOM LEADS		TOP LEADS			BOTTOM LEADS		TOP LEADS	
		Polar-ity	Starts	Ends	Polar-ity		Polar-ity	Starts	Ends	Polar-ity		Polar-ity	Starts	Ends	Polar-ity
6	8	↑	$A1_1$ = 1	$A1_2$ = 27	↓	8	↑	$B1_1$ = 52	$B1_2$ = 78	↓	7	↑	$C1_1$ = 19	$C1_2$ = 60	↓
	7	↓	$A2_1$ = 24	$A2_2$ = 65	↑	8	↓	$B2_1$ = 75	$B2_2$ = 101	↑	8	↓	$C2_1$ = 57	$C2_2$ = 83	↑
	8	↑	$A3_1$ = 47	$A3_2$ = 73	↓	7	↑	$B3_1$ = 83	$B3_2$ = 124	↓	8	↑	$C3_1$ = 65	$C3_2$ = 91	↓
	8	↓	$A1_3$ = 70	$A1_4$ = 96	↑	8	↓	$B1_3$ = 121	$B1_4$ = 9	↑	7	↓	$C1_3$ = 88	$C1_4$ = 129	↑
	7	↑	$A2_3$ = 93	$A2_4$ = 134	↓	8	↑	$B2_3$ = 6	$B2_4$ = 32	↓	8	↑	$C2_3$ = 126	$C2_4$ = 14	↓
	8	↓	$A3_3$ = 116	$A3_4$ = 4	↑	7	↓	$B3_3$ = 14	$B3_4$ = 55	↑	8	↓	$C3_3$ = 134	$C3_4$ = 22	↑

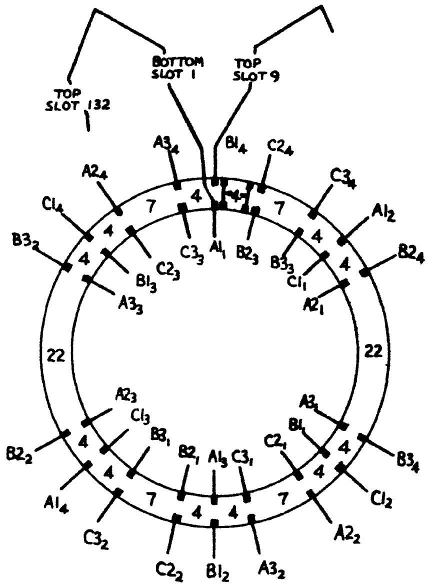


Fig.8-22. Working Diagram for 138 slots, 18 poles, spp = 2 5/9

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A3_1$ $A3_2 \rightarrow A3_4$ $A3_3 \rightarrow A2_3$ $A2_4 \rightarrow A1_4$	$A1_3$	$A1_3 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B3_1$ $B3_2 \rightarrow B3_4$ $B3_3 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$	$B1_3$	$B1_3 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C3_1$ $C3_2 \rightarrow C3_4$ $C3_3 \rightarrow C2_3$ $C2_4 \rightarrow C1_4$	$C1_1$	$C1_1 \rightarrow A1_1$
2	$A1_1 \rightarrow A3_4$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A3_1$ $A3_3 \rightarrow A2_3$ $A2_4 \rightarrow A1_4$	$A1_3 \rightarrow A3_2$	$A1_3 \rightarrow A3_2 \rightarrow B1_1 \rightarrow B3_4$
	$B1_1 \rightarrow B3_4$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B3_1$ $B3_3 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$	$B1_3 \rightarrow B3_2$	$B1_3 \rightarrow B3_2 \rightarrow C1_3 \rightarrow C3_2$
	$C1_3 \rightarrow C3_2$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C3_1$ $C3_3 \rightarrow C2_3$ $C2_4 \rightarrow C1_4$	$C1_1 \rightarrow C3_4$	$C1_1 \rightarrow C3_4 \rightarrow A1_1 \rightarrow A3_4$

TABLE 8-23

Connection Table for 150 Slots, 18 Poles, spp=2 7/9; $(y=17;\ y_b=8;\ y_f=9;\ a=+3;\ d=9)$

REFERENCE WORKING DIAGRAM Fig. 8-23

No. of Parts per Phase	No. of Coils per Part	PHASE A				No. of Coils per Part	PHASE B				No. of Coils per Part	PHASE C			
		TOP LEADS		BOTTOM LEADS			TOP LEADS		BOTTOM LEADS			TOP LEADS		BOTTOM LEADS	
		Polarity	Starts	Ends	Polarity		Polarity	Starts	Ends	Polarity		Polarity	Starts	Ends	Polarity
6	9	↑	$A1_1$ = 1	$A1_2$ = 145	↓	8	↑	$B1_1$ = 140	$B1_2$ = 117	↓	8	↑	$C1_1$ = 4	$C1_2$ = 131	↓
	8	↓	$A2_1$ = 26	$A2_2$ = 3	↑	8	↓	$B2_1$ = 15	$B2_2$ = 142	↑	9	↓	$C2_1$ = 12	$C2_2$ = 6	↑
	8	↑	$A3_1$ = 51	$A3_2$ = 28	↓	9	↑	$B3_1$ = 23	$B3_2$ = 17	↓	8	↑	$C3_1$ = 37	$C3_2$ = 14	↓
	9	↓	$A1_3$ = 76	$A1_4$ = 70	↑	8	↓	$B1_3$ = 65	$B1_4$ = 42	↑	8	↓	$C1_3$ = 79	$C1_4$ = 56	↑
	8	↑	$A2_3$ = 101	$A2_4$ = 78	↓	8	↑	$B2_3$ = 90	$B2_4$ = 67	↓	9	↑	$C2_3$ = 87	$C2_4$ = 81	↓
	8	↓	$A3_3$ = 126	$A3_4$ = 103	↑	9	↓	$B3_3$ = 98	$B3_4$ = 92	↑	8	↓	$C3_3$ = 112	$C3_4$ = 89	↑

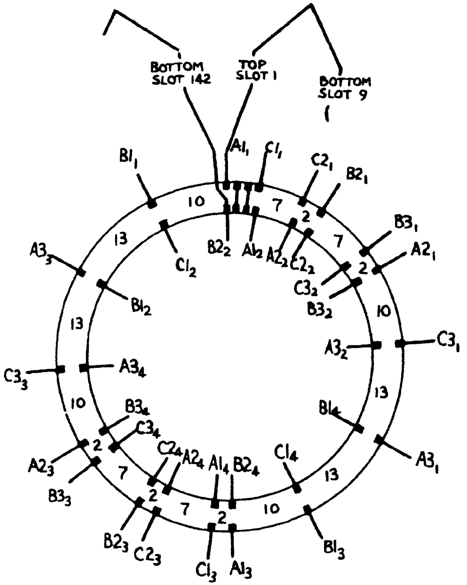


Fig.8-23. Working Diagram for 150 slots, 18 poles, spp = 2 7/9

CONNECTION OF PARTS

No.of Parallel Circuits	Connection to Rings	Jumper Connections	Star Connection	Delta Connection
1	$A1_1$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A3_1$ $A3_2 \rightarrow A3_4$ $A3_3 \rightarrow A2_3$ $A2_4 \rightarrow A1_4$	$A1_3$	$A1_3 \rightarrow B1_1$
	$B1_1$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B3_1$ $B3_2 \rightarrow B3_4$ $B3_3 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$	$B1_3$	$B1_3 \rightarrow C1_3$
	$C1_3$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C3_1$ $C3_2 \rightarrow C3_4$ $C3_3 \rightarrow C2_3$ $C2_4 \rightarrow C1_4$	$C1_1$	$C1_1 \rightarrow A1_1$
2	$A1_1 \rightarrow A3_4$	$A1_2 \rightarrow A2_2$ $A2_1 \rightarrow A3_1$ $A3_3 \rightarrow A2_3$ $A2_4 \rightarrow A1_4$	$A1_3 \rightarrow A3_2$	$A1_3 \rightarrow A3_2 \rightarrow B1_1 \rightarrow B3_4$
	$B1_1 \rightarrow B3_4$	$B1_2 \rightarrow B2_2$ $B2_1 \rightarrow B3_1$ $B3_3 \rightarrow B2_3$ $B2_4 \rightarrow B1_4$	$B1_3 \rightarrow B3_2$	$B1_3 \rightarrow B3_2 \rightarrow C1_3 \rightarrow C3_2$
	$C1_3 \rightarrow C3_2$	$C1_2 \rightarrow C2_2$ $C2_1 \rightarrow C3_1$ $C3_3 \rightarrow C2_3$ $C2_4 \rightarrow C1_4$	$C1_1 \rightarrow C3_4$	$C1_1 \rightarrow C3_4 \rightarrow A1_1 \rightarrow A3_4$

TABLE 8-24

FOR THE DETERMINATION OF THE WINDING PITCH AND OF THE VALUE OF a FOR VARIOUS VALUES OF THE FRACTION OF SPP

Fraction of spp = $\frac{n}{d}$	1/3	2/3	1/6	5/6	1/9	2.9	4/9	5/9	7/9	8/9	1/12	5/12	7/12
$\frac{6n + a}{d}$	2	4	1	5	1	1	3	3	5	5	0	2	4
a	0	0	0	0	+3	-3	+3	-3	+3	-3	-6	-6	+6

TABLE 8-25

WORKING DIAGRAMS AND CONNECTION TABLES ARE GIVEN FOR THE FOLLOWING POLE AND SLOT NUMBERS

No.of Slots	42	48	66	78	84	96	96	96	99	102	105	114	117	120	126	132	138	144	150	153	192	210	240
No.of Poles	Working Diagram and Connection Tables																						
6	8-1	8-8				8-6					8-17												
12			8-11	8-13	8-2		8-9			8-15				8-4							8-7	8-18	
18								8-19	8-12			8-20	8-14		8-3	8-21	8-22	8-10	8-23	8-16			
24																							8-5

CHAPTER 9

TWO AND MORE SPEED POLYPHASE WINDINGS

When it is desirable that a motor should run with two or more different speeds while connected to a source of power of constant frequency, special or several stator windings are to be used which permit a change in the number of poles (see Eq. 1-1). In order to avoid a larger number of slip rings, the rotor is, in these cases, normally of squirrel-cage type. Several cases are to be considered.

9-1. Two speeds with the Ratio 2 to 1. When 2 synchronous speeds with the ratio 2:1 are desirable, the numbers of poles must have the ratio 1:2. For example, if the synchronous speeds 1800 and 900 are necessary, the winding must be able to produce the pole numbers 4 and 8, or, if the synchronous speeds 600 and 300 are necessary, the winding must be able to produce the pole numbers 10 and 20, and so forth. The pole ratio 1:2 can be accomplished by a single winding (called consequent-pole winding).

With respect to the smaller number of poles, i.e., with respect to the higher speed, this winding is a lap winding connected top-to-bottom by long jumpers (see Art. 3-3 and Fig. 3-31). The N-poles and S-poles are separately connected together making 2 winding parts per phase, each of which contains (number of poles/2) pole-phase groups (see Eq. 1-4). The coil pitch of this winding is small; it must be as close as possible to half of the pole pitch.

Double the number of poles is achieved by changing the current direction in one of the 2 parts of each phase by reconnecting the parts. The pole pitch becomes half of that of the winding with the smaller number of poles. Since a pole-phase group covers 1/3 of a pole pitch of the latter or high-speed winding, it covers 2/3 of a pole pitch of the winding with the larger number of poles or slow-speed winding. Thus, there are 3 pole-phase groups in 2 poles for the larger number of poles (3-zone winding) and 6 pole-phase groups in 2 poles for the smaller number of poles (6-zone winding). Furthermore, the coil pitch is close to a full pole pitch of the winding with the larger number of poles, because it is close to half the pole pitch of the winding with the smaller number of poles.

Consider, for example, a 3-phase winding for 4 and 8 poles with 72 slots. The total number of pole-phase groups of this winding is 4 x 3 = 12. Each pole-phase group consists of 72/12 = 6 single coils, and the coil pitch is as close as possible to (3 x 6)/2 = 9 slot pitches (1→10). Fig. 9-1 shows the 12-pole phase groups and the phases to which they are assigned. Consider phase A. Of the 4 pole-phase groups of this phase, 1, 4, 7 and 10, pole-phase groups 1 and 7 which lie under poles of the same polarity are connected in series and also the groups 4 and 10 which lie under poles of opposite polarity are connected in series making 2 winding parts in each phase. Fig. 9-2a shows a 2-parallel star connection of this winding which yields 4 poles, since the connection (Fig. 9-1) is entirely normal for a 4-pole winding (see Chapter 3). In phase A, the current has in the pole-phase groups 1 and 7, and 10 and 4 the direction from 1 to 7 and 10 to 4, respectively.

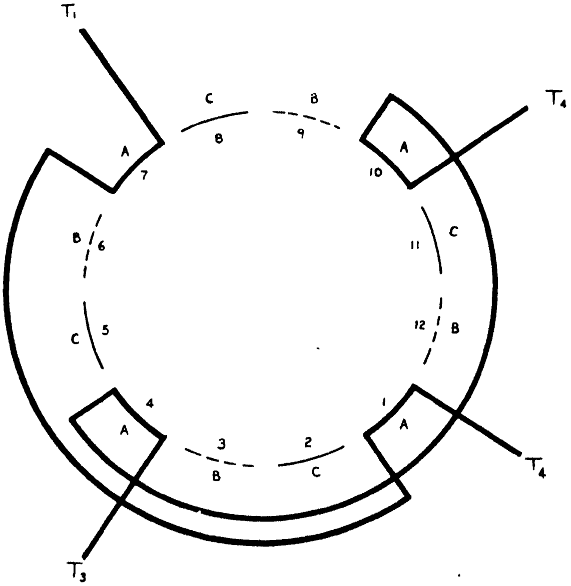


Fig. 9-1. Pole phase groups of a 4/8-pole winding. Top-to-bottom connection. Each phase has two winding parts. Phase A only shown.

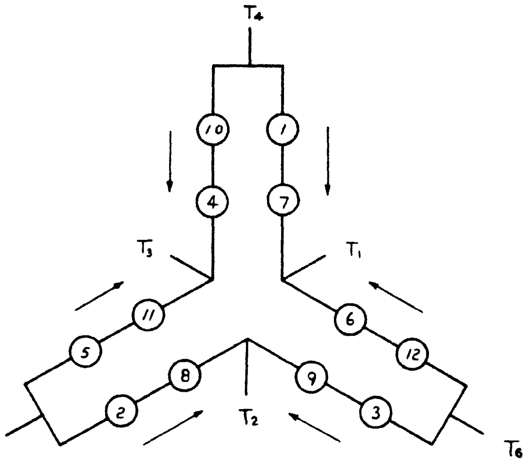
The larger number of poles, 8, can be achieved by connecting the 12 pole-phase groups in a single delta, as shown in Fig. 9-2b. In comparison to Fig. 9-2a, the current is reversed in the pole-phase groups 4 and 10, 6 and 12, 2 and 8. This connection will yield 8 poles.

The double star-single delta connection used in Figs. 9-2a and 9-2b in order to change the number of poles is applicable to *constant torque* motors in which the torque is the same at both speeds, as it is, for example, when a motor drives an air compressor. The horsepower rating of such motors varies in proportion to speed, i.e., it has the ratio 2:1. For *variable torque* motors, i.e., for drives in which the torque decreases with decreasing speed, the double star-single star connection is used, in order to change the numbers of poles. An example of such a drive is a ventilating fan for which the horsepower rating at the higher speed is about the third power of that at the lower speed. On the other hand, for *constant horsepower* motors in which the horsepower rating is the same at both speeds, the single delta-double star connection is used, in order to change the number of poles. An example of a drive of this kind is a drill press.

The 3 kinds of connections applied to 2-speed motors with the speed ratio 2:1 are shown in the first row of Table 9-1 and in Figs. 9-4 to 9-19. It should be noted that in each of the connections, the numbers of stars or deltas can be doubled, tripled, and so forth. So for constant torque, for example, 4 parallel stars-2 parallel deltas can be used instead of double star-single delta. Such a connection is shown in Fig. 9-19.

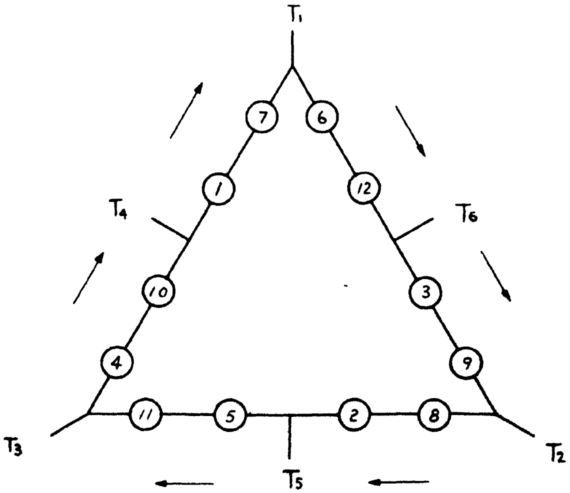
Table 9-2 gives the numbers of the Connection Diagrams given in this chapter for the speed ratio 2:1.

9-2. Two Speeds with a Ratio Different from 2 to 1. When 2 synchronous speeds with a ratio different from 2 to 1 are desirable, for example, with the ratio 2 to 3, 3 to 4, and so forth, 2 separate windings are to be used. Two normal 2 layer windings making a 4 layer winding are used for small motors, but for larger motors, 2 *inter-laced* windings arranged as per Fig. 9-3. are used. The coils indicated by A belong to one winding; the coils indicated by B belong to the other winding.



4 pole connection. Lines connect to T_4, T_5, T_6. T_1, T_2, T_3 connect together.

Fig. 9-2a. Schematic Diagram for the 4/8-pole winding of Fig. 9-1. 2Y connection for the high speed (4-poles).



8 pole connection. Lines connect to T_1, T_2, T_3. T_4, T_5, T_6 are open.

Fig. 9-2b. Schematic Diagram for the 4/8-pole winding of Fig. 9-1. Single-delta connection for the low speed (8-poles).

The 2 coil sides in each slot belong to both windings, one to each. Only half of the coils are used at one time. The connections of the 2 windings are made on opposite ends of the motor. The total number of slots is an even number.

The coils of both windings must have approximately the same depth and exactly the same coil pitch. Since the top coil sides of the A-winding lie in the odd slots and those of the B-winding in the even slots, the coil pitch must be equal to an odd number of slot pitches in order that coil sides of both windings lie in each slot. The coil pitch is usually smaller than the pole pitch of the winding with the smaller number of poles and larger than the pole pitch of the winding with the larger number of poles. Two examples will be considered.

(a) Speed ratio 3:2, i.e., pole ratio 2:3. Number of poles 8 and 12, number of slots = 144. The pole pitch of the 8-pole winding is equal to 144/8 = 18 slot pitches and that of the 12-pole winding to 144/12 = 12 slot pitches. A coil pitch of 13 slot pitches (1→14) can be chosen yielding a coil width equal to (13/18) x 100 = 72.2% of the pole pitch of the 8-pole winding and to (13/12)x100 = 108.2% of the pole pitch of the 12-pole winding.

(b) Speed ratio 7:5, i.e., pole ratio 5:7. Number of poles 10 and 14, number of slots = 168. The pole pitch of the 10-pole winding is equal to 168/10 = 16 4/5 slot pitches and that of the 14-pole winding to 168/14 = 12 slot pitches. A coil pitch of 13 slot pitches (1→14) can be chosen yielding a coil width equal to (13/16.8)x 100 = 77.4% of the pole pitch of the 10-pole winding and (13/12)x 100 = 108.2% of the pole pitch of the 14-pole winding.

The inter-laced windings can be integral or fractional slot. Since only one of the two windings is connected to the lines at at one time, the winding not in use must be made inactive, i.e., if connected series delta, the delta must be opened at one corner; if parallel connected (star or delta) the parallel paths of each phase must be opened. This is done to avoid harmful circulating currents. Hence, most two winding designs are series star or series delta connected; the delta, in all cases, must be opened when not in use. This is shown in the second row of Table 9-1.

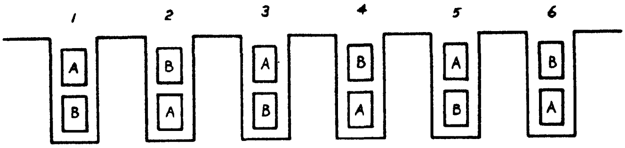


Fig. 9-3. Arrangement of 2 interlaced windings for two speeds with ratio different from 2 to 1.

9-3. Three Speeds, 2 of Which Have the Ratio 2 to 1. When 3 synchronous speeds are desirable, 2 of which have the ratio 2 to 1, 2 interlaced windings are to be used as described in Art. 9-2. However, the 2 to 1 speed ratio winding is to be made with the top-to-bottom connection between the pole-phase groups by means of long jumpers, as described in Art. 9-1, and the connection of the winding parts must correspond to the application constant horsepower, constant torque, or variable torque; the other winding can be made with normal connections (top-to-top or bottom-to-bottom). The remarks made in Art. 9-2 regarding circulating currents in 2-winding motors also apply here. The connections for this case are shown in the third row of Table 9-1. The most common pole combinations are 4/6/8, 6/8/12, 8/12/16, and 12/16/24.

9-4. Four Speeds with 2 Pairs Having the Ratio 2 to 1. When 4 synchronous speeds are desirable with 2 pairs each of which has the ratio 2 to 1, 2 different windings are to be used. There are 2 different ways in which this can be accomplished: (1) The windings of the kind described in Art. 9-1 are arranged in 4 layers, the upper 2 layers belonging to one winding and the lower 2 layers belonging to the other winding. (2) Two interlaced windings of the kind described in Art. 9-2 are used, each winding is wound in alternate slots, and both are connected top-to-bottom by long jumpers. A typical pole combination is 6/8/12/16. The connections of 4-speed windings for the different applications are shown in the fourth row of Table 9-1.

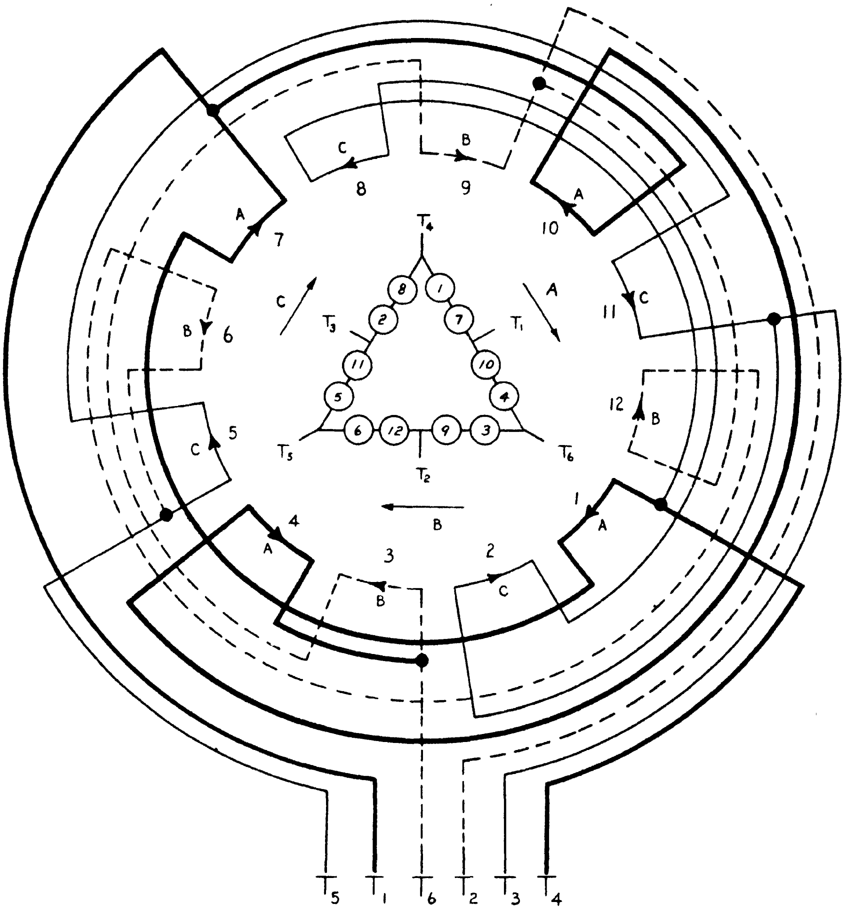


Fig. 9-4. Constant horsepower Connection Diagram for the pole ratio 4/8.

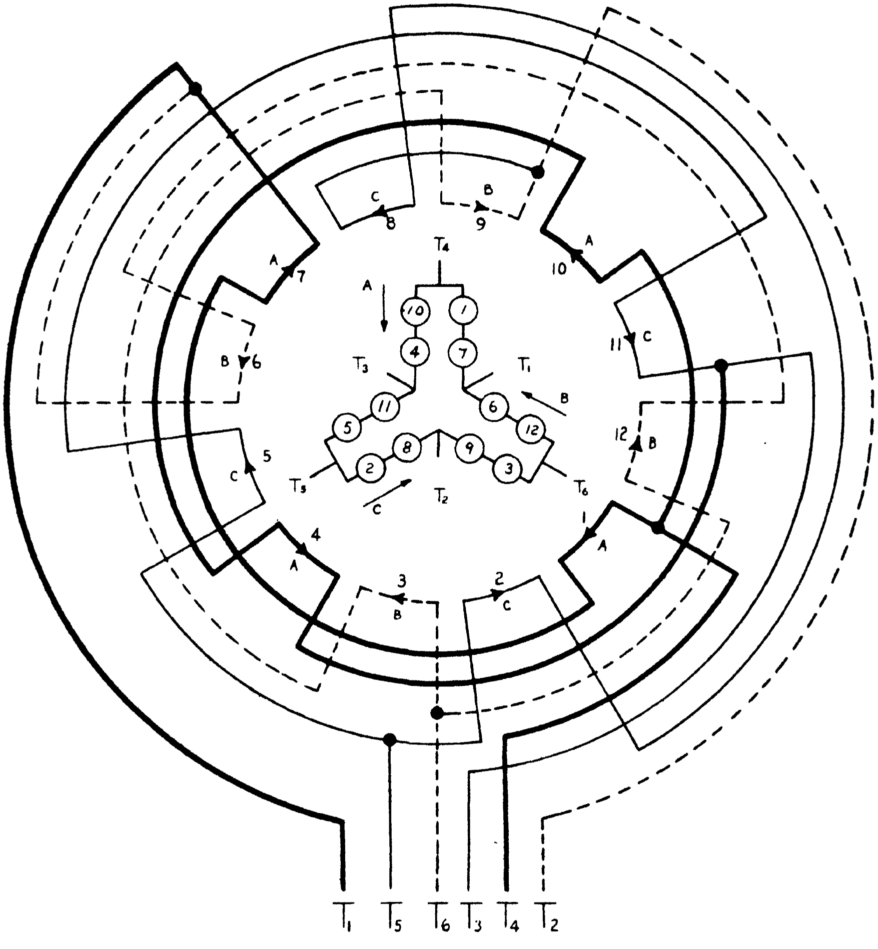


Fig. 9-5. Constant torque Connection Diagram for the pole ratio 4/8.

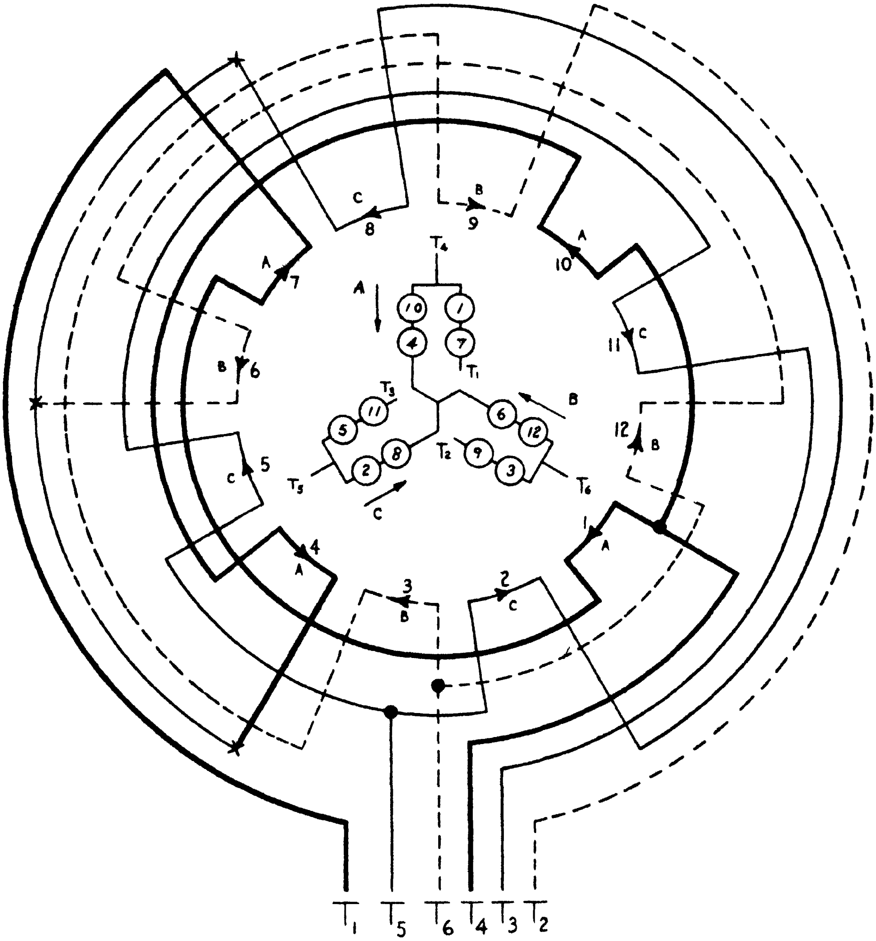


Fig. 9-6. Variable torque Connection Diagram for the pole ratio 4/8.

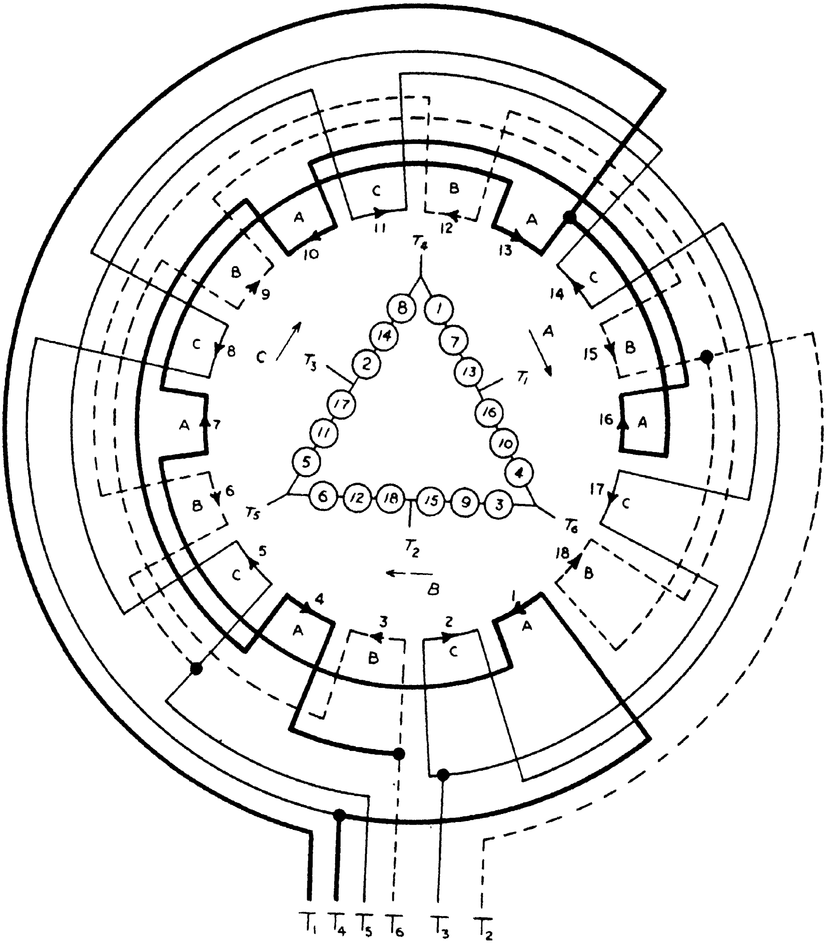


Fig. 9-7. Constant horsepower Connection Diagram for the pole ratio 6/12.

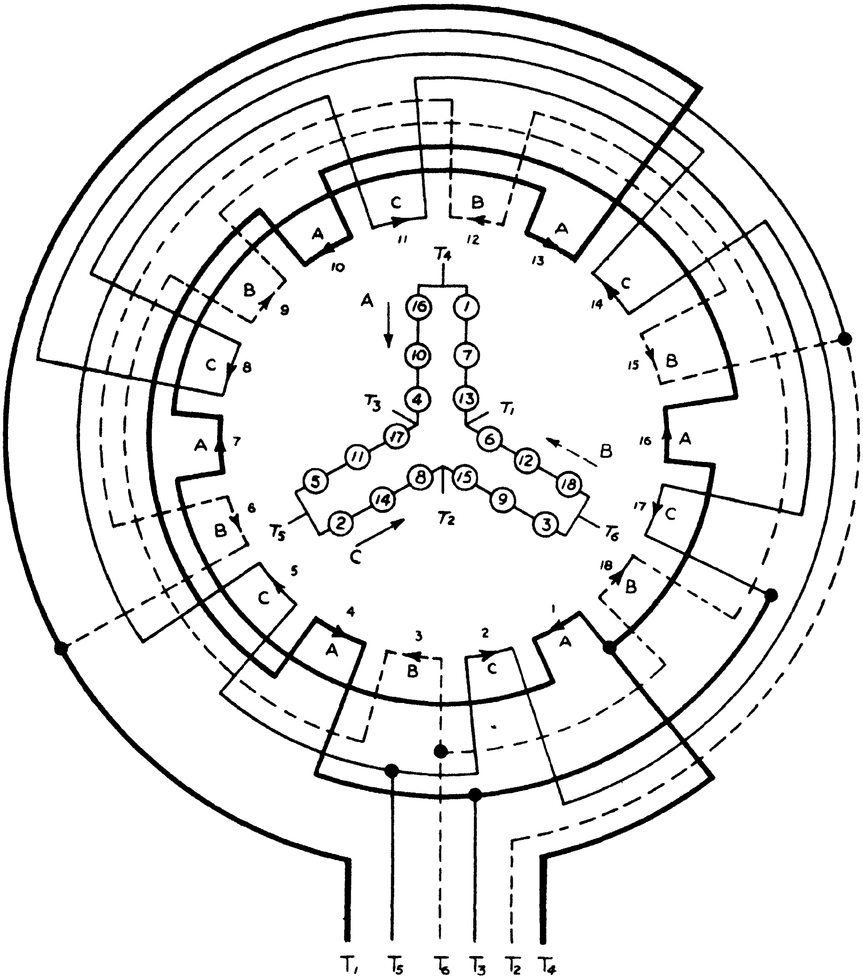


Fig. 9-8. Constant torque Connection Diagram for the pole ratio 6/12.

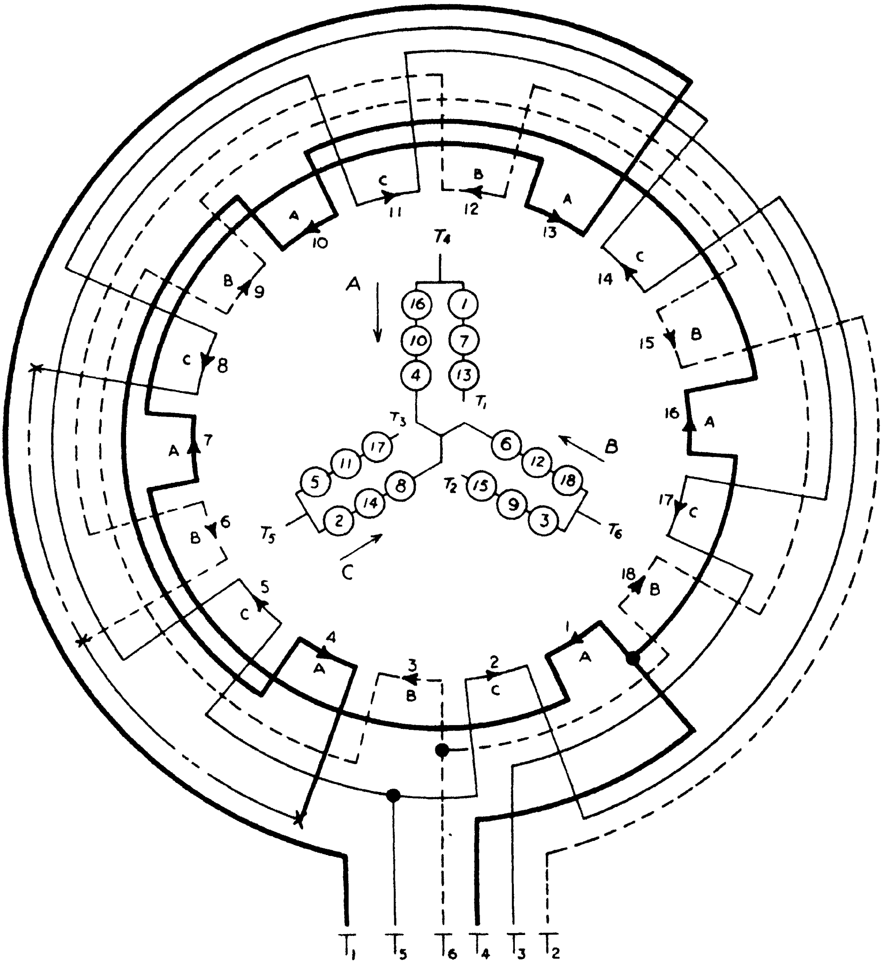


Fig. 9-9. Variable torque Connection Diagram for the pole ratio 6/12.

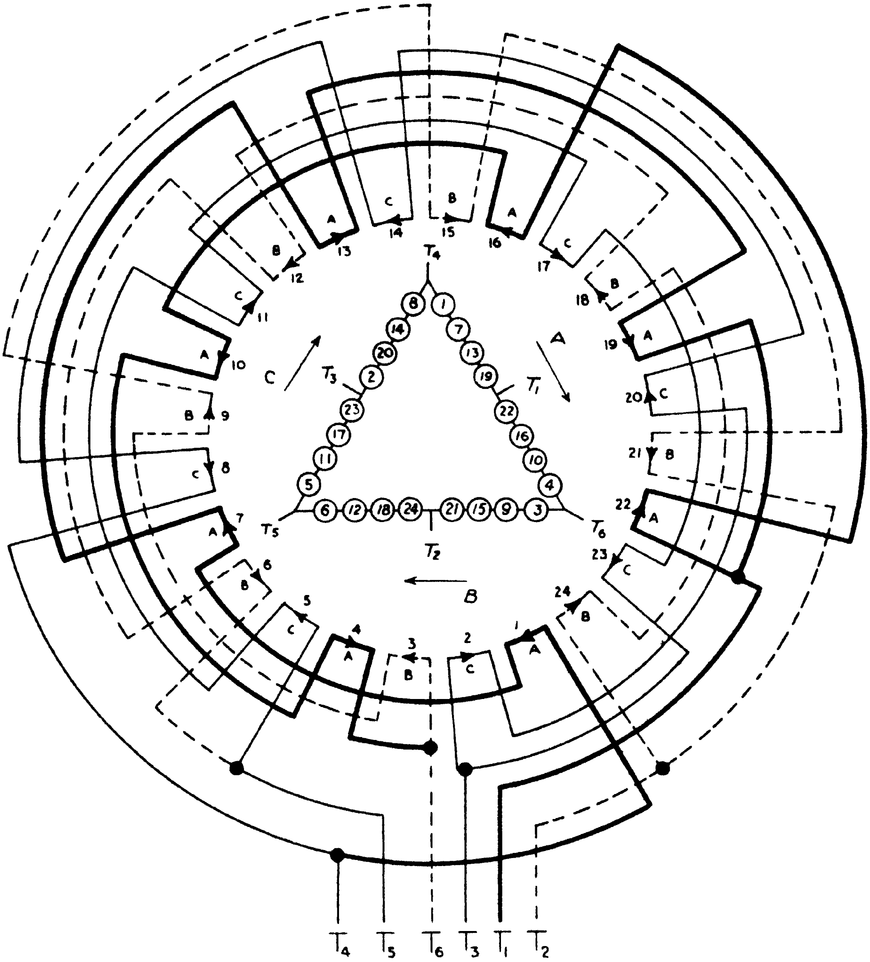


Fig. 9-10. Constant horsepower Connection Diagram for the pole ratio 8/16.

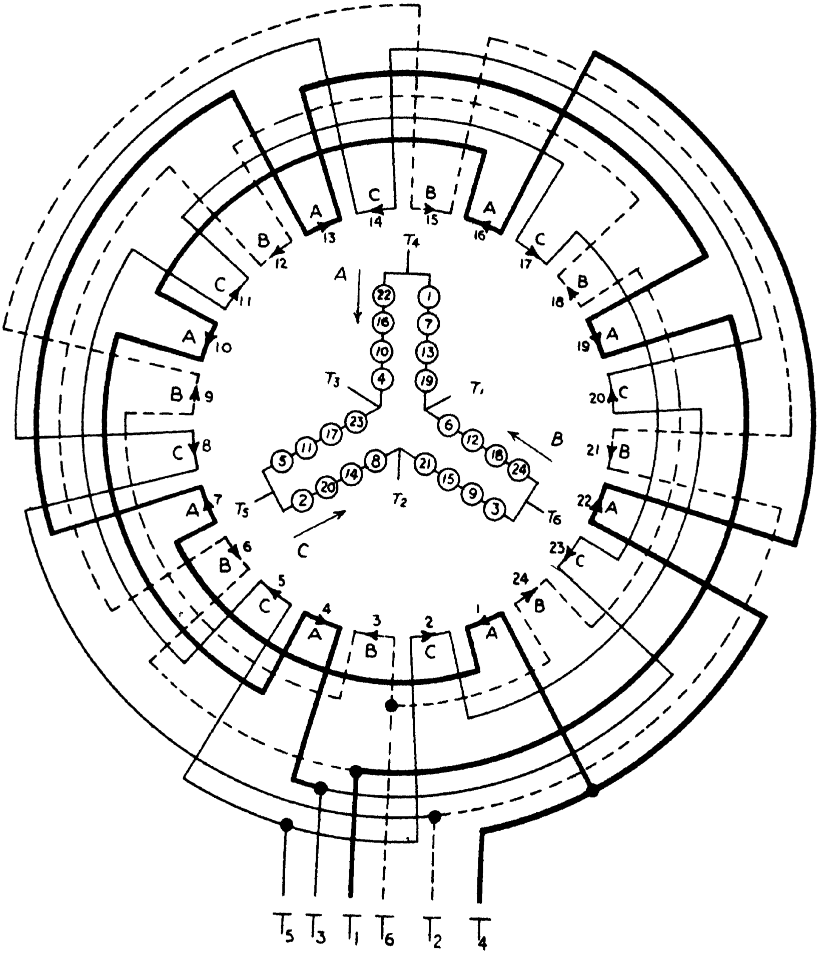


Fig. 9-11. Constant torque Connection Diagram for the pole ratio 8/16.

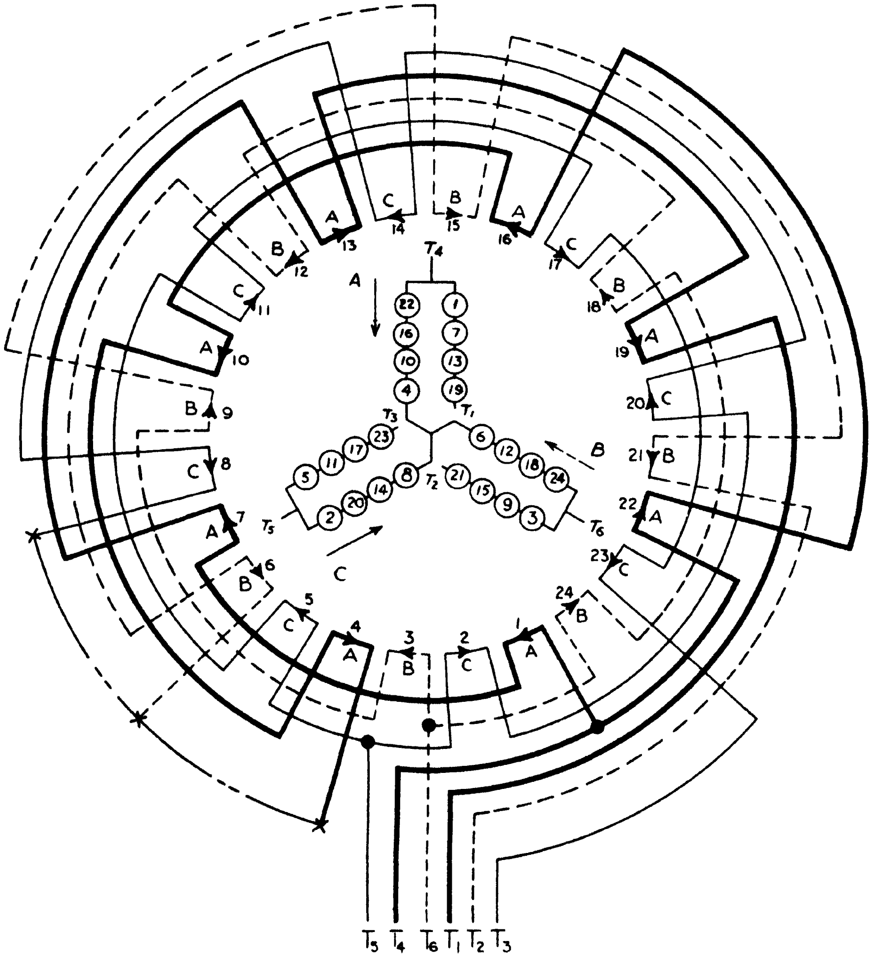


Fig. 9-12. Variable torque Connection Diagram for the pole ratio 8/16.

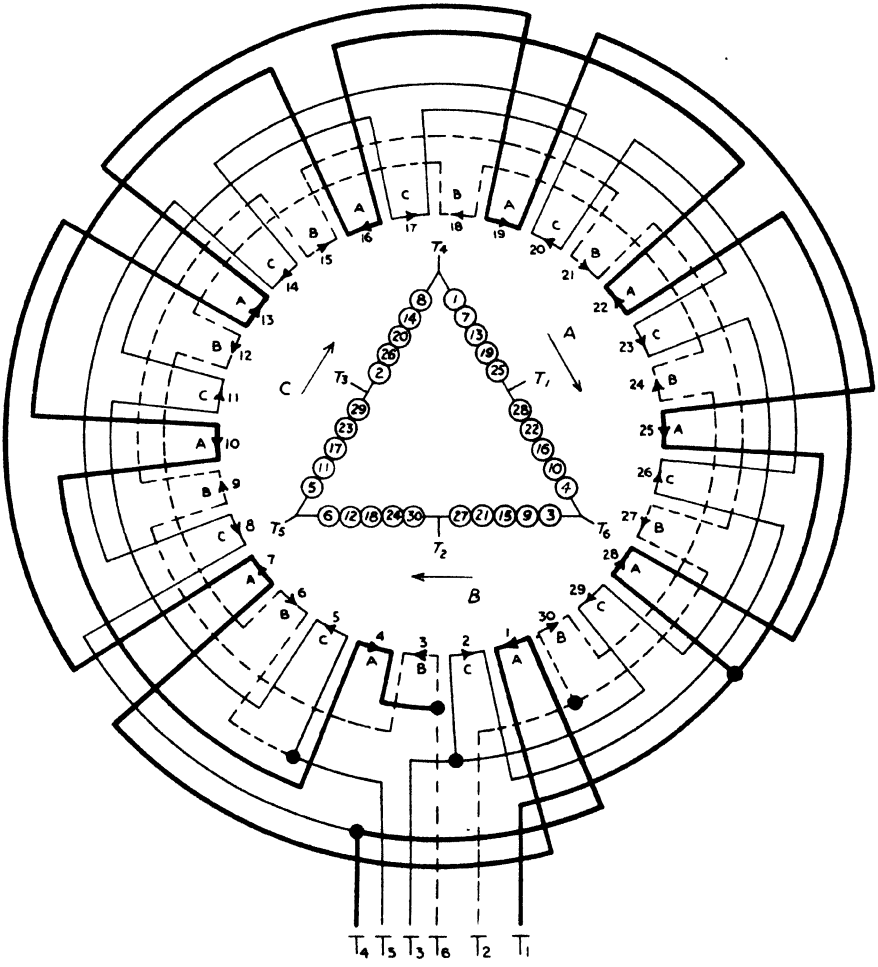


Fig. 9-13. Constant horsepower Connection Diagram for the pole ratio 10/20.

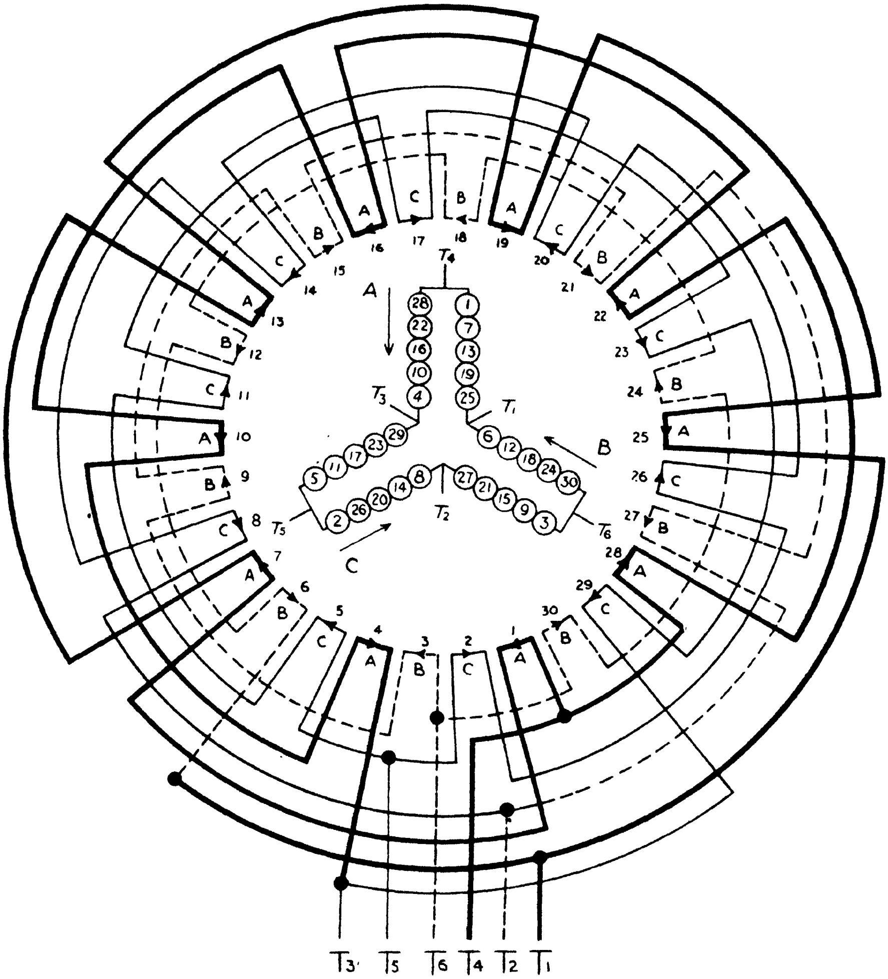


Fig. 9-14. Constant torque Connection Diagram for the pole ratio 10/20.

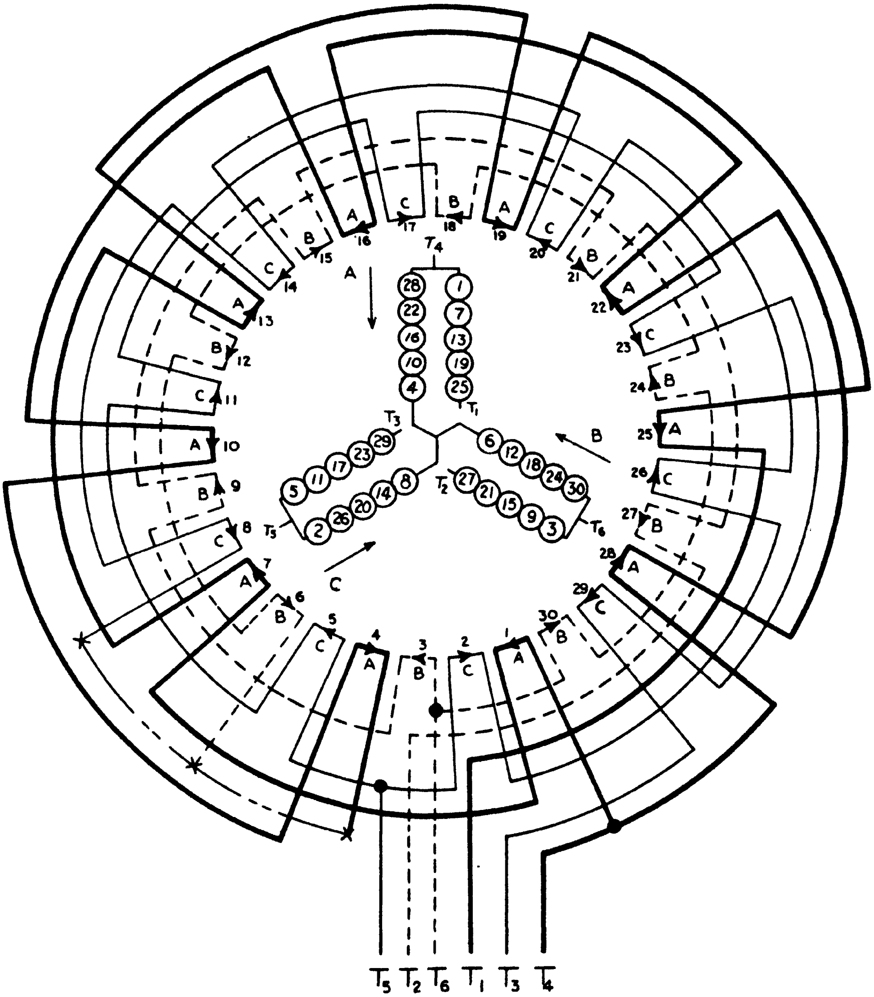


Fig. 9-15. Variable torque Connection Diagram for the pole ratio 10/20.

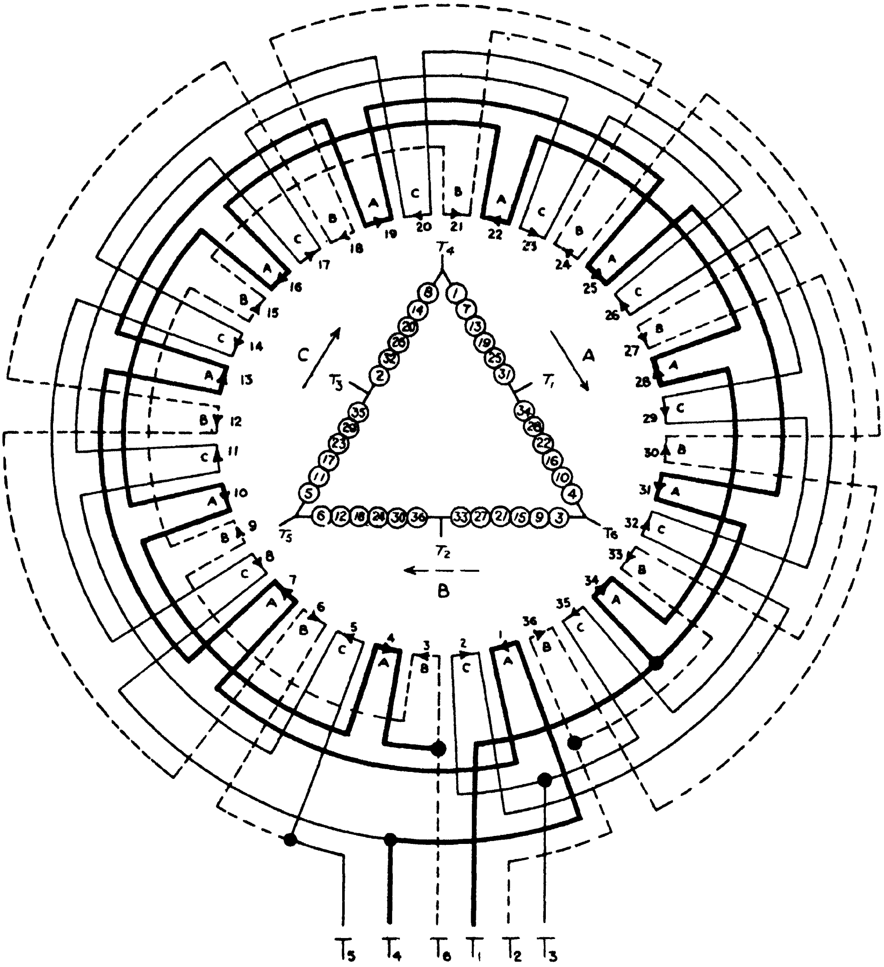


Fig. 9-16. Constant horsepower Connection Diagram for the pole ratio 12/24.

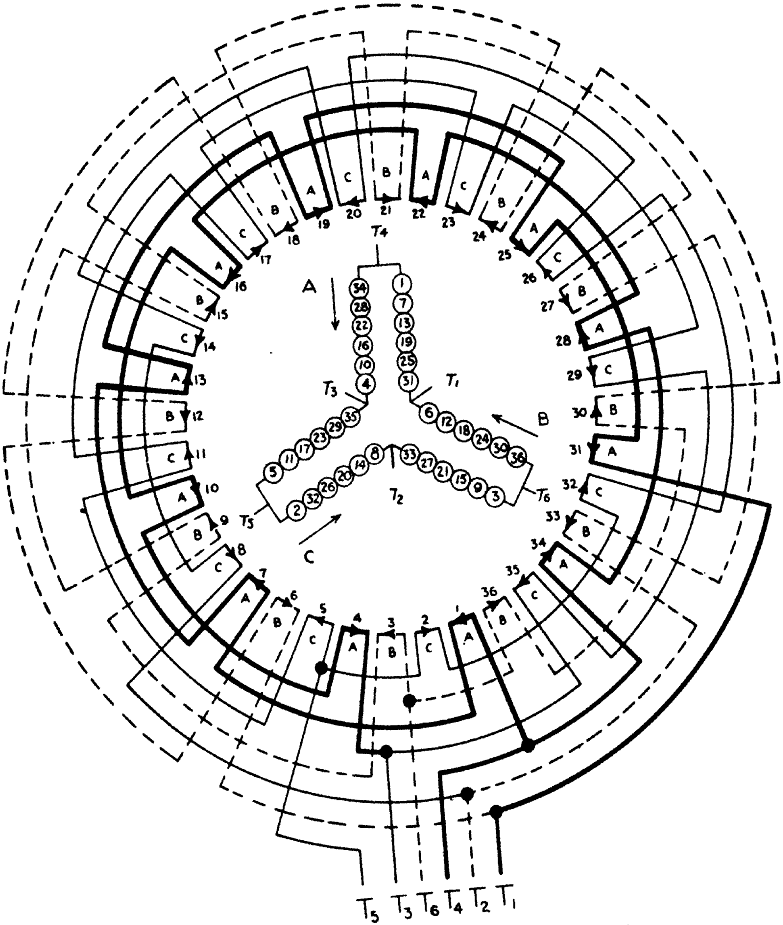


Fig. 9-17. Constant torque Connection Diagram for the pole ratio 12/24.

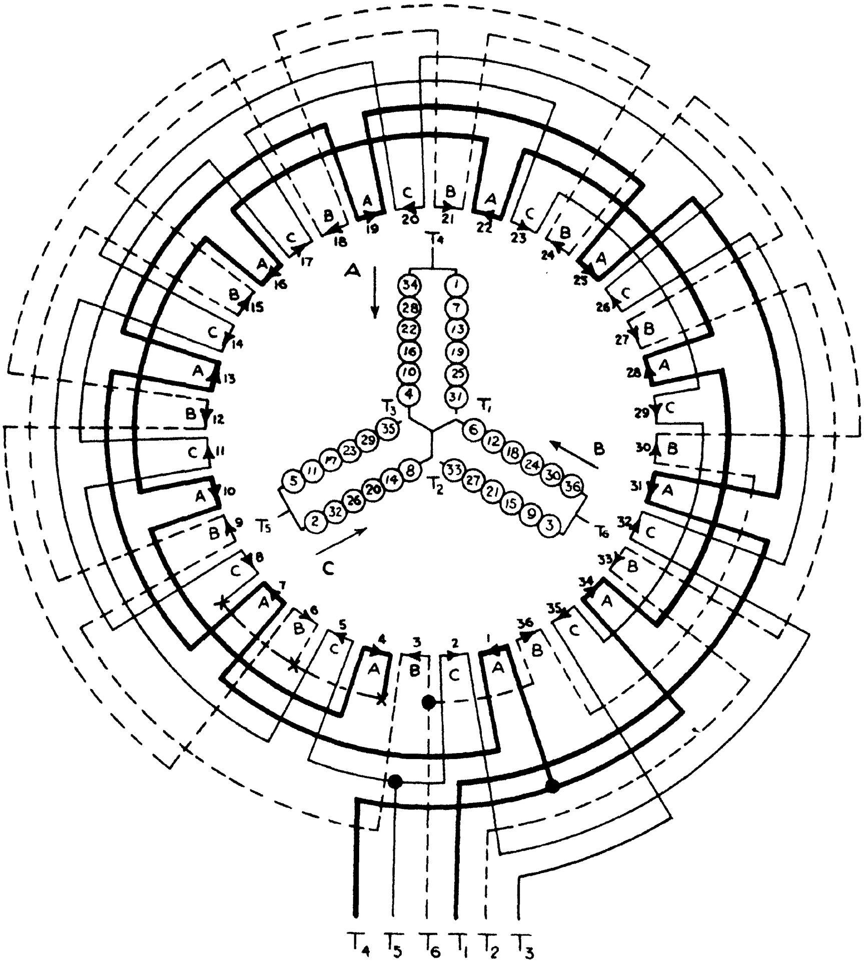


Fig. 9-18. Variable torque Connection Diagram for the pole ratio 12/24.

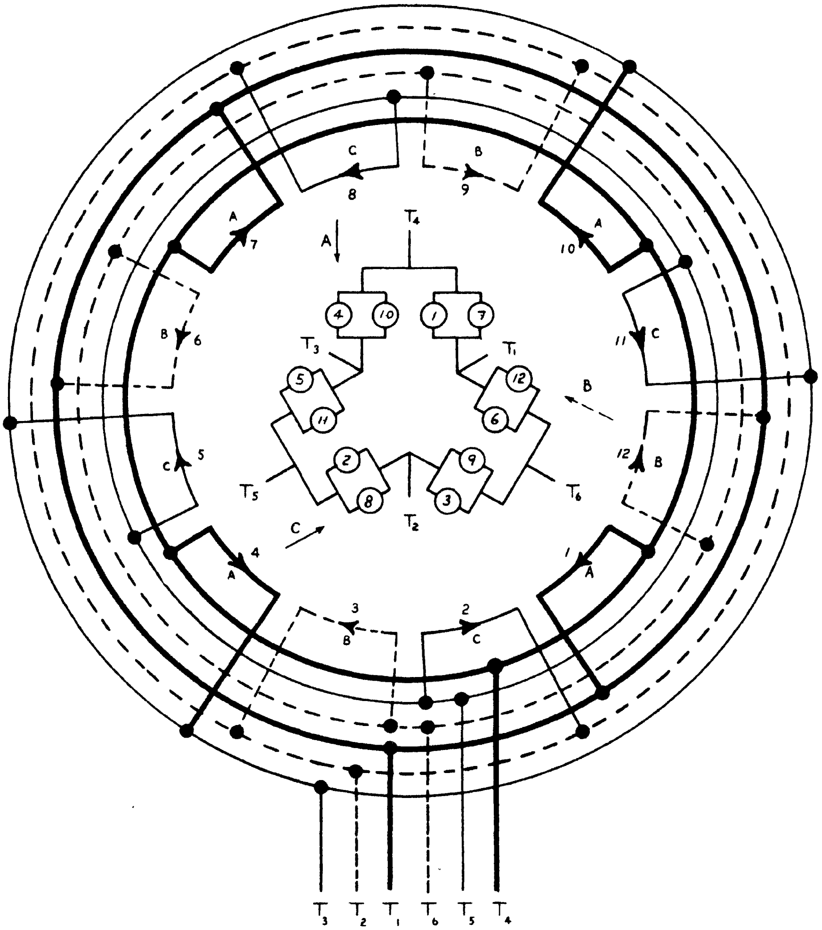
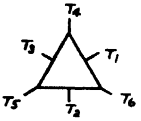


Fig. 9-19. Constant torque Connection Diagram for the pole ratio 4/8 with 4 parallel star-2 parallel delta connections.

TABLE 9-1

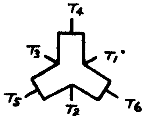
Table of Connection Schemes for Multi-Speed Squirrel Cage Induction Motors

THREE-PHASE, TWO-SPEED, ONE-WINDING
CONSTANT HP



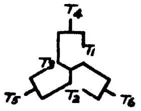
Speed	L_1	L_2	L_3	Open	Together
1 Low	T_1	T_2	T_3		T_4, T_5, T_6
2 High	T_6	T_4	T_5	T_1, T_2, T_3	

THREE-PHASE, TWO-SPEED, ONE-WINDING
CONSTANT TORQUE



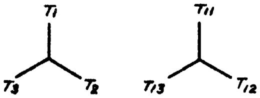
Speed	L_1	L_2	L_3	Open	Together
1 Low	T_1	T_2	T_3	All Others	
2 High	T_6	T_4	T_5		T_1, T_2, T_3

THREE-PHASE, TWO-SPEED, ONE-WINDING
VARIABLE TORQUE



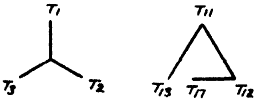
Speed	L_1	L_2	L_3	Open	Together
1 Low	T_1	T_2	T_3	All Others	
2 High	T_6	T_4	T_5		T_1, T_2, T_3

THREE-PHASE, TWO-SPEED, TWO-WINDING
CONSTANT HP, INTERLACED WINDING



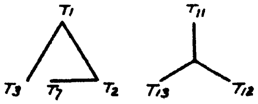
Speed	L_1	L_2	L_3	Open
1 Low	T_1	T_2	T_3	T_{11}, T_{12}, T_{13}
2 High	T_{11}	T_{12}	T_{13}	T_1, T_2, T_3

THREE-PHASE, TWO-SPEED, TWO-WINDING
CONSTANT TORQUE, INTERLACED WINDING



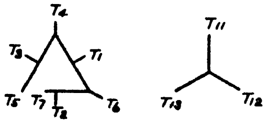
Speed	L_1	L_2	L_3	Open
1 Low	T_1	T_2	T_3	$T_{11}, T_{12}, T_{13}, T_{17}$
2 High	T_{11}	T_{12}	T_{13}, T_{17}	T_1, T_2, T_3

THREE-PHASE, TWO-SPEED, TWO-WINDING
VARIABLE TORQUE. INTERLACED WINDING



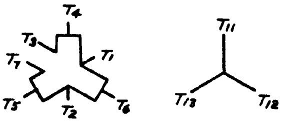
Speed	L_1	L_2	L_3	Open
1 Low	T_1	T_2	T_3, T_7	T_{11}, T_{12}, T_{13}
2 High	T_{11}	T_{12}	T_{13}	T_1, T_2, T_3, T_7

THREE-PHASE, THREE-SPEED, TWO-WINDING
CONSTANT HP



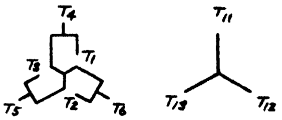
Speed	L_1	L_2	L_3	Open	Together
1 Low	T_1	T_2	T_3	All Others	T_4, T_5, T_6, T_7
2nd	T_6	T_4	T_5, T_7	All Others	
3 High	T_{11}	T_{12}	T_{13}	All Others	

THREE-PHASE, THREE-SPEED, TWO-WINDING
CONSTANT TORQUE



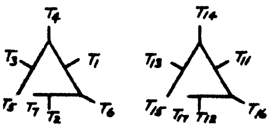
Speed	L_1	L_2	L_3	Open	Together
1 Low	T_1	T_2	T_3, T_7	All Others	
2nd	T_6	T_4	T_5	All Others	T_1, T_2, T_3, T_7
3 High	T_{11}	T_{12}	T_{13}	All Others	

THREE-PHASE, THREE-SPEED, TWO-WINDING
VARIABLE TORQUE



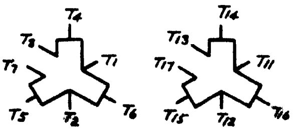
Speed	L_1	L_2	L_3	Open	Together
1 Low	T_1	T_2	T_3	All Others	
2nd	T_6	T_4	T_5	All Others	T_1, T_2, T_3
3 High	T_{11}	T_{12}	T_{13}	All Others	

THREE-PHASE, FOUR-SPEED, TWO-WINDING
CONSTANT HP



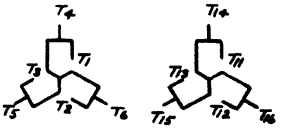
Speed	L_1	L_2	L_3	Open	Together
1 Low	T_1	T_2	T_3	All Others	T_4, T_5, T_6, T_7
2nd	T_{11}	T_{12}	T_{13}	All Others	$T_{14}, T_{15}, T_{16}, T_{17}$
3rd	T_6	T_4	T_5, T_7	All Others	
4 High	T_{16}	T_{14}	T_{15}, T_{17}	All Others	

THREE-PHASE, FOUR-SPEED, TWO-WINDING
CONSTANT TORQUE



Speed	L_1	L_2	L_3	Open	Together
1 Low	T_1	T_2	T_3, T_7	All Others	
2nd	T_{11}	T_{12}	$T_{13,17}$	All Others	
3rd	T_6	T_4	T_5	All Others	T_1, T_2, T_3, T_7
4 High	T_{16}	T_{14}	T_{15}	All Others	$T_{11}, T_{12}, T_{13}, T_{17}$

THREE-PHASE, FOUR-SPEED, TWO-WINDING
VARIABLE TORQUE



Speed	L_1	L_2	L_3	Open	Together
1 Low	T_1	T_2	T_3	All Others	
2nd	T_{11}	T_{12}	T_{13}	All Others	
3rd	T_6	T_4	T_5	All Others	T_1, T_2, T_3
4 High	T_{16}	T_{14}	T_{15}	All Others	T_{11}, T_{12}, T_{13}

Courtesy of G.W. Heumann of the
General Electric Company, Schenectady, N.Y.

TABLE 9-2

TABLE SHOWING THE NUMBERS OF CONNECTION DIAGRAMS GIVEN IN THIS CHAPTER FOR A SPEED RATIO OF 2:1.

Pole Ratio	4/8		6/12	8/16	10/20	12/24
Type of Connection	Connection Diagram Number					
Constant Horsepower	9-4		9-7	9-10	9-13	9-16
Constant Torque	9-5	9-19	9-8	9-11	9-14	9-17
Variable Torque	9-6		9-9	9-12	9-15	9-18

4-parallel star for 8 poles and 2-parallel delta for 4 poles.

CHAPTER 10

RECONNECTING AN OLD POLYPHASE WINDING FOR NEW CONDITIONS AND REWINDING AN OLD CORE

The points of importance for reconnecting an old winding or rewinding an old core are different depending upon whether the voltage, the frequency, the speed, or the number of phases is to be changed.

10-1. Relation Between Voltage, Flux, Number of Turns, and Frequency. A magnetic flux and an armature with current-carrying conductors are the 2 indispensable parts of each electric machine. In the induction motor, the flux is produced by the stator winding and the rotor is the armature; in the synchronous machine, the flux is produced by the rotor winding and the stator is the armature.

The magnitude of the flux is determined by the voltage of the stator winding, the number of turns in series per phase, and the line frequency.

$$\text{Voltage} = \text{Constant} \times \text{Flux per pole} \times \text{No. of turns in series per phase} \times \text{Frequency} \qquad (10\text{-}1)$$

The number of turns in series per phase is obtained from the number of turns in a single coil, the number of single coils in a pole-phase group, and the number of pole-phase groups in each circuit of the phase. The number of poles and the line frequency determine the speed of the machine (Eq. 1-1).

In a finished machine, all these quantities are fixed. When reconnecting an old winding for new conditions, care must be taken that a change in one or more of these quantities is matched by a corresponding change in some of the other quantities in such a manner that Eq. 10-1 is always satisfied. For example, the voltage of a motor can be reduced to half of its original value, if twice as many parallel circuits as in the original winding can be made. This procedure is explained in detail in Art. 10-2. It is shown there that no single quantity can be changed at random.

The torque of the electric machine is determined by the flux per pole, the number of poles, the number of conductors of the armature, and the current in each armature conductor, i.e.,

Torque = Constant x Flux per pole x No. of poles x No. of armature conductors x Armature current. (10-2)

The torque is proportional to the square of the voltage because the current and the flux are each proportional to the voltage. According to Eq. 10-1, the torque is also proportional to the square of the flux.

In the induction motor, the magnitude of the stator current depends upon the magnitude of the rotor current. The area of the conductor is determined by the magnitude of the current and the permissible current density. When changes are made in the machine, care must be taken that any increase in current density in the conductors is within admissible limits.

In the same manner that the current and area of the conductor determine the current density in the conductor, the flux and cross sections of the iron determine the flux density in the iron. When changes are made in the machine, no appreciable changes in the flux density are permissible.

The power output of a motor is given by the relation

$$\mathrm{HP} = \frac{\mathrm{Torque} \times \mathrm{rpm}}{5250} \qquad (10\text{-}3)$$

where torque is expressed in pound-feet, and the rpm is the actual speed of the motor which may be from 1% to 5% less than synchronous speed as given by Eq. 1-1. The larger percentage applies to small motors, and the smaller percentage to large motors.

When the horsepower and speed are given, Eq. 10-3 can be used for determining the torque.

10-2. Reconnecting for Another Voltage. If the new voltage is to be higher than the old, attention must be paid first to the insulation of the winding. Manufacturers follow a certain classification in the insulation of windings. The usual classification is given in Tables 2-1 and 2-4. Between 110 and 600 volts, the thickness and material of the insulation are determined more by mechanical than by electrical reasons, and a winding made for 110 volts can also be used for 600 volts. However, in the higher insulation classes, caution is necessary and it is in general, not permissible to use a lower insulation class for a higher insulation class.

When a winding is reconnected for another voltage at the same frequency, the flux must be kept close to its original value, i.e., according to Eq. 10-1, the number of turns must be changed in the same ratio as the voltage is changed.

The simplest way to adjust the number of turns of a 3-phase winding is to change a delta connection to a star connection, or vice versa. Reconnecting a winding from delta to star is equivalent to an increase of the number of turns per phase in the ratio 1.73 to 1, and vice versa; reconnecting a winding from star to delta is equivalent to a decrease of the number of turns per phase in the ratio 1/1.73 = 0.58 to 1. Therefore, a winding connected delta for 220 volts can be reconnected to star and used for 380 volts, for 380/220 = 1.73. Conversely, a winding connected star for 380 volts can be used for 220 volts delta. (380 volts as line voltage is not used in this country but it is used in Europe.)

When a winding connected star for 440 volts is reconnected to delta, the normal operating voltage would be $\frac{440}{1.73}$ = 254 volts. When operated at 220 volts, it is being operated at 220/254 = 87% of its rated voltage and, correspondingly, the flux is 87% of its original value. This means that for the same torque (see Eq. 10-2) the current is 15% higher and the copper losses 32% ($1.15^2 = 1.32$) higher than in the original winding. Furthermore, the starting and pull-out torques are only $(0.87)^2$ = 76% of the original values. It follows from this that a reduction in flux can be made only in motors which have sufficient margin to stand these reductions. If a winding connected delta for 220 volts is reconnected star for use on 440 volts, the flux becomes 16% too high; the normal voltage for the star connected winding would be 1.73 x 220 = 380 volts, and 440/380 = 1.16. The higher flux causes higher flux densities in the iron and higher iron losses. On the other hand, the higher flux increases the starting and pull-out torques by 34% ($1.16^2 = 1.34$). It is, in general, safer to increase the flux than to reduce it except in cases with sufficient margin in torques and temperature rise of the copper.

When a winding is reconnected for another voltage, use is made, in general, of changing the number of parallel circuits, since the change from star to delta, or vice versa, seldom leads to desirable results. When necessary, the change in the number of parallel circuits and the change from star to delta, or vice versa, are applied simultaneously. A winding for 220 volts having 2 parallel circuits can be used for 440 volts without changing its performance when the 2 circuits are reconnected in series. Conversely, a winding for 440 volts with all pole-phase groups in series can be used for 220 volts when 2 parallel circuits are made. Caution must be exercised when the number of parallel circuits in fractional-slot windings is changed because of the limitations in the number of permissible parallel paths of the windings. (See Arts. 4-7 and 5-2.)

If the series star connection of all pole-phase groups is shown as 100, the percentage voltage yielding the same flux for star with 2 to 5 parallel circuits and also for series and parallel delta is as follows:

Series Star 100	2 Parallel Star 50	3 Parallel Star 33	4 Parallel Star 25	5 Parallel Star 20
Series Delta 58	2 Parallel Delta 29	3 Parallel Delta 19	4 Parallel Delta 15	5 Parallel Delta 12

A deviation from this table means a change in the flux with all the consequences discussed above.

The series star connection has been chosen as a reference in the tabulation, i.e., 100% has been assigned to this connection. Any other connection, for example, 2 parallel star, series delta, etc., can also be chosen as a reference. Doing this, Table 10-1 is obtained. The use of this table will be explained by an example. A 3-phase, 12-pole motor wound for 2300 volts and connected 2-parallel star is to be reconnected for 440 volts. The new voltage is $\frac{440}{2300} \times 100 = 19.1\%$ of the original. Taking the original voltage and connection as a reference, find first the horizontal line in which there is assigned 100% to 2 parallel star (this is the second horizontal line from the top). In this horizontal line find then the figure 19 under "6 parallel

TABLE 10-1. PERCENTAGE VOLTAGE OF VARIOUS 3-PHASE CONNECTIONS

Series Star	2 Parallel Star	3 Parallel Star	4 Parallel Star	5 Parallel Star	6 Parallel Star	Series Delta	2 Parallel Delta	3 Parallel Delta	4 Parallel Delta	5 Parallel Delta	6 Parallel Delta
100	50	33	25	20	17	58	29	19	15	12	10
200	100	67	50	40	33	115	58	39	29	23	19
300	150	100	75	60	50	173	87	58	43	35	29
400	200	133	100	80	67	231	115	77	58	46	39
500	250	167	125	100	83	289	144	96	72	58	48
600	300	200	150	120	100	346	173	115	87	69	58
173	86	58	43	35	29	100	50	33	25	20	17
346	173	115	87	69	58	200	100	67	50	40	33
519	260	173	130	104	87	300	150	100	75	60	50
692	346	231	173	138	115	400	200	133	100	80	67
865	433	288	216	173	144	500	250	167	125	100	83
1038	519	346	260	208	173	600	300	200	150	120	100

delta." This means that reconnected in 6 parallel delta, the motor can be used for 440 volts.

10-3. Reconnecting for Another Frequency. The most common changes of frequency are from 25 cycles to 60 cycles and vice versa, from 60 cycles to 50, and from 40 cycles to 60 or vice versa. According to Eq. 1-1, the speed will change in proportion to the frequency, if the number of poles remains the same. If the speed is to remain the same or nearly the same as before, the number of poles must be changed in the same ratio as the frequency is changed. For example, if the line frequency of a 6-pole motor is changed from 25 to 60 cycles, its synchronous speed will be $\frac{60}{25} \times \left(\frac{120 \times 25}{6}\right) = \frac{60}{25}(500) = 1200$ rpm, and if its speed is to remain nearly the same as before, i.e., nearly 500 rpm, the number of poles must be changed either from 6 to 14, yielding $\frac{120 \times 60}{14} = 514$ rpm, or from 6 to 16, yielding $\frac{120 \times 60}{16} = 450$ rpm. Thus, 2 possibilities are to be considered: (a) when the speed changes in proportion to the frequency, and, (b) when the speed remains the same or nearly the same as before.

(a) The speed changes in proportion to the frequency. When a motor previously connected to a line of low frequency, say 25-cycle line, is to be connected to a line of higher frequency, say to a 40-cycle or 60-cycle line, a mechanical problem arises. Due to the higher speed at the higher frequency, the mechanical stresses on the rotor are higher than before. In these cases, the manufacturer of the motor is to be consulted in order to determine whether the rotor is able to stand the higher mechanical stresses. Also, it may be necessary to adjust the gearing or belting to the new conditions.

Aside from the mechanical problem, two cases are possible: (1) it may be desirable that the torque is the same for both frequencies, or (2) that the horsepower is the same for both frequencies. In the first case, the horsepower changes in the same ratio as the speed (Eq. 10-3), and the flux must be the same for both frequencies (Eq. 10-2). In the second case, the torque changes inversely to the change in speed (Eq. 10-3), and the flux must change with the square root of the ratio of the frequencies.

Considering first the case of constant torque, i.e., of constant flux, it follows from Eq. 10-1 that the voltage must change in the same ratio as the frequency changes. This is seldom the case and a reconnection of the winding is usually necessary to achieve more or less constant flux. This will be explained by several examples.

Consider a 60-HP, 6-pole series delta-connected motor on a 25-cycle, 220-volt line. This motor is to be used on a 60-cycle, 440-volt line with approximately the same torque as before. The synchronous speed at the 60-cycle line will be 1200 rpm. Since the frequency is $\frac{60}{25} = 2.4$ times the previous value, the voltage at 60 cycles should be $2.4 \times 220 = 528$ volts, in order that the flux and the torque remain the same as before. At 440 volts, the flux will be $440/528 = 0.83$, i.e., 83% and, at the same current as before, the torque will be only $\left(\frac{440}{528}\right)^2 = 0.7.$, i.e., only 70% of the previous value.

However, if the motor is reconnected 2-parallel star, corresponding to a 25-cycle line voltage of $\frac{\sqrt{3}}{2} \times 220 = 190$ volts, the voltage at 60 cycles for constant flux must be $190 \times \frac{60}{25} = 456$ volts and the motor can be used for constant torque on the 60-cycle, 440-volt line. The power output on the 60-cycle line will be $2.4 \times 60 = 144$ HP.

Assume that the 25-cycle, 220-volt motor considered in the previous example is to be connected to a 220-volt, 60-cycle line, i.e., both line voltages are equal. In this case, the winding can be reconnected 2-parallel delta, corresponding to a 25-cycle line voltage of $220/2 = 110$ volts and to a 60-cycle line voltage of $110 \times 2.4 = 264$ volts. At 220 volts and 60 cycles, the flux will be $\left(\frac{220}{264}\right) = 0.83$, and the torque $(0.83)^2 = 0.7$ of the original values. The power output is $0.7 \times 2.4 \times 60 = 101$ HP. Taking into account the better ventilation due to the higher speed, a somewhat larger current, i.e., larger torque (Eq. 10-2), can be admitted, and the power output is then about twice the original value.

Consider a 60-cycle, 220-volt motor which is to be connected to a 25-cycle, 220-volt line. The voltage which corresponds to 25 cycles at constant flux is $\frac{25}{60}\,220 = 91.5$ volts. If the motor originally is connected 2-parallel star or 2-parallel delta, a series connection of the 2-parallel circuit would correspond to 2 x 220 = 440 volts at 60 cycles, and the voltage at 25 cycles and constant flux should be $\frac{25}{60}$ 440 = 183 volts. Since a higher flux density is permissible at 25 cycles than at 60 cycles, such a motor will operate satisfactorily in many cases on a 220-volt line.

A change from 50 to 60 cycles at the same voltage and approximately constant flux can be achieved by reconnecting the original winding from a 6-zone winding to a 3-zone winding. This has the effect of changing the distribution factor from approximately 0.957 to 0.83, which nearly compensates for the change from 50 to 60 cycles (See Appendix 5).

Considering the second case when the horsepower rating is to be the same at both frequencies, the torque changes inversely to the ratio of the frequencies. Since the torque is proportional to the square of the flux, the latter must change inversely to the square root of the ratio of the frequencies. Then according to Eq. 10-1 the voltage must also change in the ratio of the square root of the ratio of the frequencies. This will be explained by an example.

Consider a 60-cycle, 220-volt motor which is to be connected to a 50-cycle, 220-volt line. The horsepower should be approximately the same at both frequencies. Then the torque at 50 cycles must be (Eq. 10-3) 60/50 of the original torque and the flux must be (Art. 10-1) $\sqrt{60/50} = 1.1$ of the original flux. If the flux would remain the same as before, the voltage at 50 cycles should be 50/60 times the voltage at 60 cycles. Since the flux changes in the ratio $\sqrt{60/50}$, the voltage at 50 cycles must be (Eq. 10-1) $50/60 \times \sqrt{60/50} = \sqrt{50/60} = \frac{1}{1.1}$. It follows from this as a rule that, for constant horsepower, the voltage must change with the square root of the ratio of the frequencies. Thus, for the motor considered, the voltage at 50 cycles should be $220 \times \frac{1}{1.1} = 200$ volts. If the motor was directly connected to the 50-cycle, 220-volt line, the torque and power would be apparently too high. If the motor originally was connected 2-parallel star, a reconnection to delta would make the voltage, at 60 cycles, $220 \times \frac{2}{\sqrt{3}} = 254$ volts, and the corresponding voltage at 50 cycles becomes $254 \times \frac{1}{1.1} = 231$ volts, which is closer to the line voltage of 220 volts than 200 volts.

When a 50-cycle motor is to be connected to a 60-cycle line, the voltage at 60 cycles, for the same horsepower at both frequencies, should be equal to the voltage at 50 cycles x $\sqrt{60/50}$. If the voltage at 50 cycles is 440 volts, the voltage at 60 cycles should be 440 x 1.1 = 484 volts. If the motor is connected series delta, a reconnection to 2-parallel star will make the voltage at 50 cycles equal to 440 x $\frac{\sqrt{3}}{2}$ = 380 volts, and at 60 cycles equal to 380 x 1.1 = 418 volts. In this case, the motor can be connected to a 60-cycle, 440-volt line.

(b) The speed remains the same at both frequencies. It has been explained above that this can be achieved only when the winding is reconnected for another number of poles. This kind of reconnection is treated in Art. 10-5.

10-4. Effective Number of Turns. Distribution Factor and Pitch Factor.

The number of turns per phase is an important factor in Eq. 10-1. As mentioned already, it depends upon the number of turns in a single coil, the magnitude of spp, the number of pole-phase groups in the phase (i.e., the number of poles), and the number of parallel circuits. However, not the real value of spp but its effective value is to be considered. The latter is equal to the real value times the distribution factor which is always smaller than 1. For example, a 3-phase winding with spp = 4 has a distribution factor equal to 0.958, and the effective number of spp is 4 x 0.958 = 3.83. With this quantity, the value of turns is to be calculated.

The distribution factors of 3-phase and 2-phase windings for different values of spp are given in Fig. A5-1. Note that the 3-zone windings are used only for two or more speed motors (See Appendix 5). For fractional-slot windings, the same curves of Fig. A5-1 can be used, provided that the numerator N of spp is used in place of spp. For example, the distribution factor of a winding with spp = 2 1/2 = 5/2 is found in Fig. A5-1 as the value which corresponds to spp = 5.

There is another factor which usually reduces the real number of turns. This is the pitch or chord factor. This factor which also is smaller than one is caused by the chording of the winding. As mentioned previously (see Art. 1-8), the coil pitch is made approximately equal to the pole pitch, except in

2-pole machines where it is 55% to 65% of the pole pitch. When the coil pitch is smaller than the pole pitch, the turn is not able to embrace the total pole flux and is less effective than when the coil pitch is equal to the pole pitch. Consider, for example, a 3-phase winding with spp = 4, i.e., 12 slots per pole. When the coil pitch is equal to 12 slot pitches (throw 1 and 13), the pitch factor is equal to 1. When the coil pitch is equal to 10 slot pitches (throw 1 and 11), the pitch factor is equal to 0.965 and the real number of turns is reduced by 3.5%. When the coil pitch is larger than the pole pitch, the turn embraces the total flux of one pole and a part of the flux of the adjacent pole of different polarity. The total flux embraced by the turn is again smaller than that of a full-pitch winding and the pitch factor is to be taken into account.

The values of the pitch factors for different ratios of coil width (coil span) to pole pitch (both measured in slot pitches) are given in Fig. A5-2.

10-5. Reconnecting for Another Speed. The reconnection for another speed by changing the number of poles becomes necessary in two cases. The first case occurs when a motor designed for a certain frequency is to be connected to a line of a different frequency and the speed of the motor is to be different from that which corresponds to the new line frequency. An example of this case is given in the beginning of Art. 10-3. The second case occurs when a motor designed for a certain line frequency and speed is to run on a line of the same frequency, but with a different speed. The latter case is the more important.

When a motor designed for a certain speed is to operate at a considerably higher speed, the mechanical problem mentioned in Art. 10-3 arises and is to be solved in the manner explained there.

A winding arranged for a certain number of poles has a fixed coil span corresponding to the pole pitch. When the number of poles is changed, the coil span remains the same but the pole pitch changes. The ratio of coil width to pole pitch and with it the chord factor of the reconnected winding are, therefore, different from those of the original winding. The chord factor determines the number of effective turns per phase (see Art.

10-4), and it may happen that the reconnected winding has a much smaller number of effective turns per phase than the original winding.

Furthermore, a motor designed for a certain number of poles has a fixed flux per pole and fixed flux densities in the air gap and in the iron. When the winding is reconnected for another number of poles, the flux density in the air gap will be left approximately the same, i.e., the flux will change approximately inversely to the change of the number of poles. For example, a 4-pole motor reconnected for 8 poles will have a flux per pole which is approximately half of that of the 4-pole motor.

The difference in the numbers of effective turns per phase and the difference in the magnitude of the flux per pole make it necessary to apply to the reconnected winding a voltage which is different from the original line voltage. Unless these differences can be matched by an additional reconnection of the motor winding, special taps on the transformer feeding the motor will be required. This will be explained by an example in which the horsepower developed at the different speeds also will be determined.

Consider a 100-HP, 4-pole, 3-phase, 60-cycle motor connected to a 220-volt line. The total number of slots is 48, i.e., spp = 4. The coil width is equal to 10 slot pitches making the ratio of coil width to pole pitch W/t = 10/12 = 0.833. This motor is to be reconnected for 6 poles. The speed will drop from 1750 to 1160. The number of slots per pole will be $\frac{48}{6} = 8$, and the ratio of coil width to pole pitch is W/t = 10/8 = 1.25. The chord factor of the original winding is 0.966 (see Fig. A5-2), and the chord factor of the reconnected winding is 0.924. The pole pitch of the reconnected winding is 4/6 = 2/3 of the original winding. Therefore, the flux of the reconnected winding, for constant flux density in the air gap, is 2/3 of the original flux. Assuming the flux of the 4-pole machine to be 1, then the product of flux times chord factor is 1 x 0.966 = 0.966 for the 4-pole winding and 2/3 x 0.924 = 0.616 for the 6-pole winding. The voltage at 4 poles is 220 volts. Therefore, the voltage at 6 poles for constant flux density must be (0.616/0.966) x 220 = 140 volts.

The same procedure of calculation has been applied to a reconnection for 8 poles. The results are given in the following tabulation:

Number of poles	4	6	8
Speed (rpm)	1750	1160	860
Coil width in slot pitches. . . .	10	10	10
Pole pitch in slot pitches. . . .	12	8	6
Ratio of coil width to pole pitch	0.833	1.25	1.667
Chord factor.	0.966	0.924	0.50
Relative flux	1	4/6	4/8
Relative flux x chord factor. . .	0.966	0.616	0.25
Voltage	220	140	57

If the original 4-pole winding is connected delta, it can be reconnected star requiring 380 volts at 4 poles, 241 volts at 6 poles, and 98 volts at 8 poles. The 6-pole winding may then operate satisfactorily at a 220-volt line.

In general, it may be desirable to increase or decrease somewhat the voltage as obtained from the calculation. An increase may be necessary with respect to the starting torque or pull-out torque, when the winding is reconnected for a higher number of poles. A reduction of the voltage may be necessary, when the winding is reconnected for a lower number of poles, since, otherwise, the flux density in the core may become too high (the depth of the core behind the teeth must increase with decreasing number of poles).

Power output equals the product of the number of phases, volts per phase, current per phase, power factor, and efficiency. Reconnecting a winding without changing the connections between phases and the number of parallel paths, the phase current is the same for all numbers of poles. The power factor and efficiency decreases somewhat with increasing number of poles. Neglecting the change in power factor and efficiency, the power output will vary as the voltage and for the motor considered is:

Number of poles	4	6	8
Horsepower.	100	64	26

The 8-pole reconnection is here impractical because of the small chord factor. A small chord factor not only reduces the power output but also distorts the flux distribution. As a result of this distortion, locking torques and noise may occur. Windings with a chord factor smaller than 0.7 should not be used.

The winding reconnected for 6 poles has spp = $\frac{48}{3 \times 6}$ = 2 2/3. This gives a fractional-slot unbalanced winding. The coil grouping of this winding is to be made in the manner explained in Chapter 5. The insulation between phases at the end windings or the heavier insulated phase coils must be shifted corresponding to the new coil grouping.

When a winding is to be reconnected for a number of poles which is twice the original number of poles, sometimes use can be made of the top-to-bottom connection discussed in Chapter 9. Hence, for example, if the original winding is connected in parallel star, a reconnection in series star using long jumpers will double the number of poles and reduce the speed to half of the original value. Also, if the original winding is connected series delta, a reconnection in parallel star, using long jumpers, will double the number of poles and reduce the speed to half of its original value. A winding arranged in 3 zones has a distribution factor equal to 0.83 while a normal or 6-zone winding has a distribution factor close to 0.96. The chord factor of the original will determine the chord factor of the reconnected 3-zone winding. The effective number of turns in each case will be a function of the respective chord and distribution factors, and these factors must be carefully considered when reconnecting for different speeds.

It has been mentioned in Chapter 9 that in the two-speed windings the coil width must be close to half of the pole pitch of the winding with the smaller number of poles, otherwise a distortion of the flux distribution occurs which may result in locking torques and noise. The same applies here when the top-to-bottom connection is used. For example, a 4-pole winding with a coil width close to half of its pole pitch should be used in the top-to-bottom connection for 8 poles.

A well-designed motor has a proper "slot combination", i.e., its number of stator slots, number of rotor slots, and number of poles are matched in such a manner that no locking torques, no cusps and dips in the torque-speed curve, and no noise occur. If the original winding is reconnected for another number of poles, the slot combination may no longer be the proper one. Note the rule that no considerable dips in the torque-speed curve will occur, if the ratio of coil width to pole pitch is about 0.83 and the rotor is skewed one stator slot pitch.

10-6. Reconnecting for Another Number of Phases. The reconnection from 2 to 3 phases and vice versa is the only one of practical importance.

Comparing a series connected 2-phase motor with a series star-connected 3-phase motor of the same output, speed, frequency, and line voltage, the 2-phase motor has approximately 25% more turns than the 3-phase motor. Therefore, if a 2-phase series-connected winding is regrouped and reconnected in 3-phase star, the number of turns, for the same line voltage, will be about 25% too high, and the motor will show all the defects of a machine operating on 80% of normal voltage, i.e., the starting and pull-out torques will be considerably decreased and, for the same output as that of the 2-phase motor, the current and heating will be increased. Vice versa, if a 3-phase series star-connected motor is regrouped and reconnected in 2-phase series, the motor will show at the same line voltage all the defects of a machine operating on 125% of normal voltage, i.e., the flux and iron losses will increase so that the motor may overheat at a light load. If the 3-phase motor is originally connected delta instead of star, its number of turns is 1.73 times that at the star connection and, reconnected for 2-phase series, it will have, for the same line voltage, 1.73/1.25 = 1.38 times the required number of turns. The motor will show then the signs of a machine operating at 72% of its normal voltage.

Since the number of turns of the 2-phase motor for the same line voltage is larger than that of the star-connected 3-phase motor, it is possible, when reconnecting from 2 to 3 phases at the same line voltage, to adjust the number of turns for the 3 phases by cutting out and leaving dead about 20% of the turns. This does not apply in reverse, because, going from 3-phase star to 2-phase, the number of turns would have to be increased by 25% and this is not possible. The method of cutting out turns for reconnecting from 2 to 3 phases will be explained by an example. Consider a 2-phase, 4-pole motor with 72 slots. The winding has 2 x 4 = 8 pole-phase groups with 72/8 = 9 single coils in each pole-phase group. For 3 phases and the same number of poles, the number of pole-phase groups becomes 3 x 4 = 12 and, if all coils were used, the number of single coils per pole-phase group would be 72/12 = 6. By making the number of single coils per pole-phase group of the 3-phase winding 5 instead of 6, i.e., cutting out every sixth coil around the machine, the number of turns is reduced in the ratio 5 to 6 (83%), which is the right value.

It should be noted that this method of reconnection from 2 to 3 phases at the same line voltage is not too satisfactory. Since 1/6 of the coils is left dead, the amount of active copper is reduced by the same percentage and, therefore, the torque and output also will be similarly reduced.

Another method for reconnecting a motor from 2 to 3 phases at the same line voltage is the "T" or Scott 2-phase to 3-phase connection. This connection, for the motor treated above, is shown in Fig. 10-1. It is necessary that the vertical leg of the "T" has 86.6% of the turns of the horizontal leg. For this reason, in each pole-phase group of the phase making the vertical leg one coil is cut out and left dead. As indicated in the figure, all pole-phase groups of the horizontal leg have 9 single coils each while the pole-phase groups of the vertical leg have only 8 single coils each, yielding for the latter leg

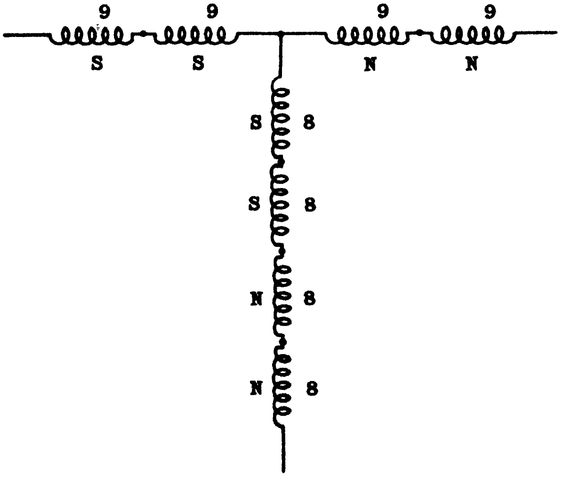


Fig. 10-1. Schematic Diagram showing the "T" or Scott connection

8/9 = 0.89 of the turns of the horizontal leg. A deviation from the 86.6% for the vertical leg leads to useless circulating currents which increase the heating. A reduction of these currents can be achieved, if the "top-to-bottom" connection (Art. 3-5) is applied to the 2 phases. In this case, in each phase, the coils of the same polarity follow each other as indicated by N and S in Fig. 10-1.

In the foregoing, reconnecting from 2 to 3 phases and vice versa for the same line voltage has been considered. When the 2-phase line voltage and the 3-phase line voltage are not equal, use can be made of the change from star to delta and vice versa, and from the change of the number of parallel circuits, as explained in Art. 10-2.

Since the 2-phase series-connected winding has at the same voltage about 25% more turns than the 3-phase series star winding, the permissible percentage voltages at the same flux are:

3-Phase Series Star	3-Phase 2-Parallel Star	3-Phase 3-Parallel Star	3-Phase 4-Parallel Star	3-Phase Series Delta	3-Phase 2-Parallel Delta	3-Phase 3-Parallel Delta	3-Phase 4-Parallel Delta	2-Phase Series	2-Phase 2-Parallels	2-Phase 3-Parallels	2-Phase 4-Parallels
100	50	33	25	58	29	19	15	80	40	27	20

The 3-phase quantities are the same as in Table 10-1. The 2-phase quantities are based upon the statement made about the ratio of turns for 2- and 3-phase. The tabulation means that if a 3-phase series star-connected motor is reconnected 2-phase series, only 80% of the 3-phase voltage should be applied to the 2-phase winding. If the 2-phase winding is connected in 2 parallel circuits, only 40% of the 3-phase voltage should be applied to it, and so forth.

The 3-phase series star connection has been chosen as reference, i.e., 100% has been assigned to this connection. As explained in Art. 10-2, any other connection can be taken as reference. Doing this for each of them, Table 10-2 is obtained, the use of which will be explained by an example.

TABLE 10-2. PERCENTAGE VOLTAGE OF VARIOUS CONNECTIONS FROM 2-PHASE TO 3-PHASE AND VICE VERSA

Three Phases										Two Phases				
Series Star	2 Parallel Star	3 Parallel Star	4 Parallel Star	5 Parallel Star	Series Delta	2 Parallel Delta	3 Parallel Delta	4 Parallel Delta	5 Parallel Delta	Series	2 Parallel	3 Parallel	4 Parallel	5 Parallel
100	50	33	25	20	58	29	19	15	12	80	40	27	20	16
200	100	67	50	40	115	58	39	29	23	161	80	54	40	32
300	150	100	75	60	173	87	58	43	35	242	121	80	60	48
400	200	133	100	80	231	115	77	58	46	323	161	108	80	64
500	250	167	125	100	289	144	96	72	58	403	202	135	100	80
173	86	58	43	35	100	50	33	25	20	139	70	47	35	28
346	173	115	87	69	200	100	67	50	40	279	139	94	70	56
519	260	173	130	104	300	150	100	75	60	418	210	139	105	84
692	346	231	173	138	400	200	133	100	80	559	279	188	139	112
865	433	288	216	173	500	250	167	125	100	698	350	233	175	139
125	63	42	31	25	72	36	24	18	15	100	50	33	25	20
250	125	84	63	50	144	72	48	36	29	200	100	67	50	40
375	188	125	94	75	216	108	72	54	43	300	150	100	75	60
500	250	167	125	100	289	144	96	72	58	400	200	133	100	80
625	313	208	156	125	360	180	120	90	72	500	250	167	125	100

A 2-phase, 440-volt, 8-pole motor connected in 4 parallel circuits is to be reconnected for 3 phases and a line voltage of 550 volts. The 3-phase voltage must be $\frac{550}{440}$ 100 = 125% of the 2-phase voltage. Taking the latter as reference, i.e., considering the horizontal row in which there is assigned 100% to "2 phases and 4 parallels", it is found that the figure 125 lies in the column marked "4 parallel star". This means that the 2-phase motor considered can be reconnected for 3 phases and connected to a 550 volt line.

If the same 2-phase motor was connected in 2 parallel circuits, the horizontal line which shows 100% under "2 phases 2 parallels" (this is the fourth horizontal line from the bottom of the Table) contains the figure 125 and the reconnection for 3 phases and 550 volts would also be possible.

10-7. Determination of Horsepower from Given Dimensions of a Motor. With fixed dimensions and speed of a machine, the output is also fixed. As has been mentioned in Art. 10-1, the torque of an electric machine is determined by the flux per pole, the number of poles, the number of armature conductors, and the current in the armature conductors. When the dimensions of a machine are fixed, only a certain flux per pole can be produced without exceeding the permissible flux densities, and only a certain number of armature conductors with a fixed current can be placed in the armature without exceeding the permissible current density. This and the speed fix the output of the machine.

The following expression applies to polyphase induction motors:

$$HP = \text{Constant} \times D^2 \times L \times \text{rpm} \qquad (10\text{-}4)$$

where D is the diameter of the stator bore, and L is the axial length (core length, including radial vents) of the laminated iron core parallel to the shaft, both in inches. For rpm, the synchronous speed is to be used. Approximate values for the constant which is called output constant are given in Fig. 10-2. This figure can be used when an old machine is to be rewound, for which the speed but not the output is known.

10-8. Rewinding an Old Core. If an old core is to be rewound for the original conditions and the data of the original winding are available, the serviceman will do best to duplicate

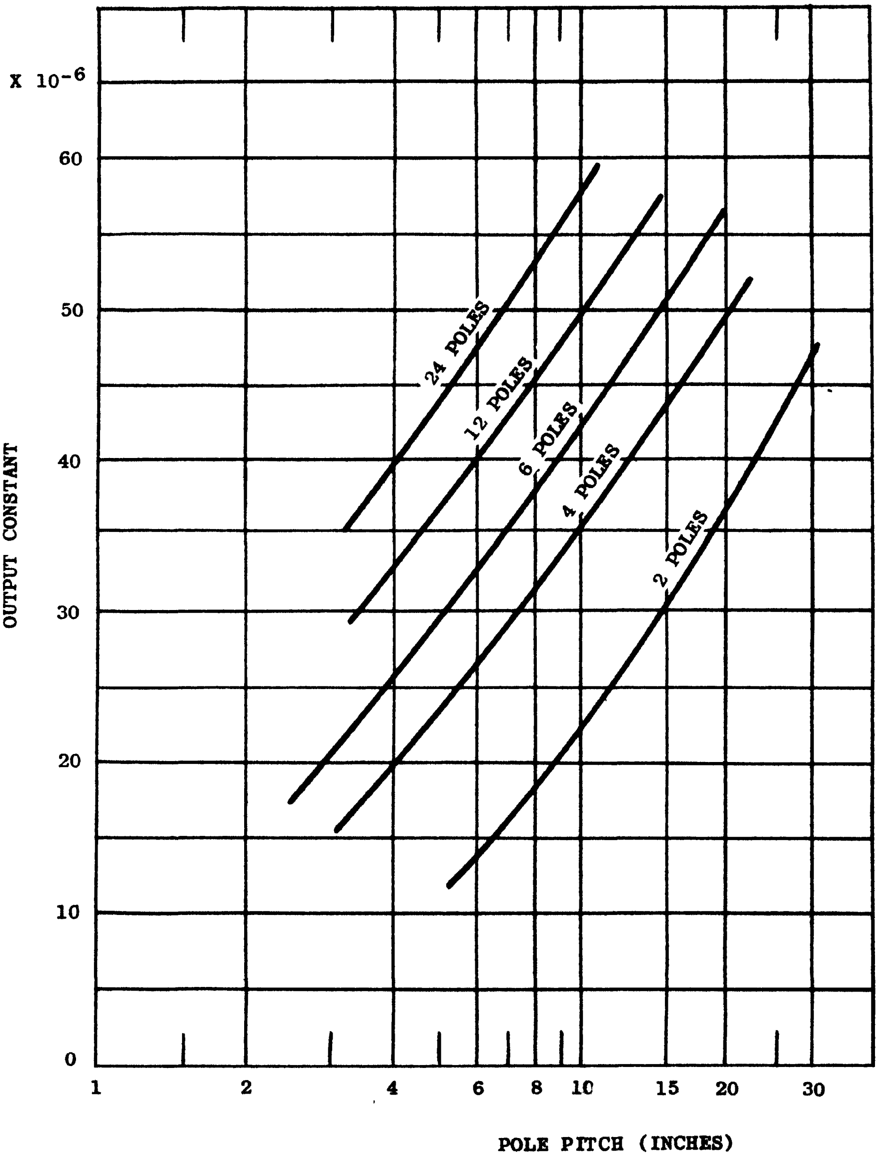


Fig. 10-2. Output constants for polyphase induction motors

the original winding. If an old core is to be rewound for the original conditions but for another voltage and the data of the original winding are available, it is easy to determine from Eq. 10-1 the necessary number of turns per phase by changing the original number of turns proportional to the new voltage. The area of the conductor must also be changed, namely, proportional to the new current. If an old core is to be rewound for conditions other than the original, for example, another output, or another speed, or another frequency, etc., a redesign of the machine is necessary. The treatment of this matter is out of the scope of this book and the reader will find an answer to this problem in the reference number 9 of the Bibliography.

CHAPTER 11

SINGLE-PHASE WINDINGS AND DIAGRAMS*

11-1. Various Types of Single-phase Motors. There are various types of single-phase motors, namely:

1. Split-phase motor.
2. Resistance-start, split-phase motor.
3. Reactor-start, split-phase motor.
4. Capacitor-start motor.
5. Permanent-split capacitor motor.
6. Two-value capacitor motor.
7. Repulsion motor.
8. Repulsion-start induction motor.
9. Repulsion-induction motor.
10. Universal motor.
11. Shaded-pole motor.
12. Split-phase reluctance motor.
13. Capacitor-type reluctance motor.
14. Capacitor-type hysteresis motor.
15. Shaded pole hysteresis motor.

The American Standards Association defines these motors as follows:

1. Split-phase Motor.

A split-phase motor is a single-phase induction motor equipped with an auxiliary winding, displaced in magnetic position from, and connected in parallel with, the main winding. (Note: Unless otherwise specified, the auxiliary circuit is assumed to be opened when the motor has attained a predetermined speed. The term "split-phase motor," used without qualification, describes a motor to be used without impedance other than that offered by the motor windings themselves, other types being separately defined.)

2. Resistance-start, split-phase motor.

A resistance-start motor is a form of split-phase motor having a resistance connected in series with the auxiliary winding. The auxiliary circuit is opened when the motor has attained a predetermined speed.

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* This chapter gives the common connection and wiring diagrams of the single-phase motors. For more detailed information on single-phase motors, the reader is referred to C. G. Veinott's book, "Fractional Horsepower Electric Motors", published by the McGraw-Hill Book Company, New York. This book contains complete and well organized information about all types of single-phase motors. The author is indebted to Mr. C.G. Veinott for some useful suggestions.

3. Reactor-start, split-phase motor.

A reactor-start motor is a form of split-phase motor designed for starting with a reactor in series with the main winding. The reactor is short-circuited,or otherwise made ineffective, and the auxiliary circuit is opened when the motor has attained a predetermined speed.

A capacitor motor is a single-phase induction motor with a main winding arranged for direct connection to a source of power and an auxiliary winding connected in series with a capacitor. (Note: The capacitor may be connected into the circuit through a transformer and its value may be varied between starting and running.)

4. Capacitor-start motor.

A capacitor-start motor is a capacitor motor in which the capacitor phase is in the circuit only during the starting period.

5. Permanent-split capacitor motor.

A permanent-split capacitor motor is a capacitor motor having the same value of capacitance for both starting and running conditions.

6. Two-value capacitor motor.

A 2-value capacitor motor is a capacitor motor using different values of effective capacitance for the starting and running conditions.

7. Repulsion motor.

A repulsion motor is a single-phase motor which has a stator winding arranged for connection to a source of power and a rotor winding connected to a commutator. Brushes on the commutator are short-circuited and are so placed that the magnetic axis of the rotor winding is inclined to the magnetic axis of the stator winding. This type of motor has a varying-speed characteristic.

8. Repulsion-start induction motor.

A repulsion-start induction motor is a single-phase motor having the same windings as a repulsion motor, but at a predetermined speed the rotor winding is short-circuited or otherwise connected to give the equivalent of a squirrel-cage winding. This type of motor starts as a repulsion motor but operates as an induction motor with constant-speed characteristics.

9. Repulsion-induction motor.

A repulsion-induction motor is a form of repulsion motor which has a squirrel-cage winding in the rotor in addition to the repulsion motor winding. A motor of this type may have either a constant-speed or varying-speed characteristic.

10. Universal motor.

A universal motor is a series-wound or a compensated series-wound motor which may be operated either on direct current or single-phase alternating current at approximately the same speed and output. These conditions must be met when the direct-current and alternating-current voltages are approximately the same and the frequency of the alternating current is not greater than 60 cycles per second.

11. Shaded-pole motor.

A shaded-pole motor is a single-phase induction motor provided with an auxiliary short-circuited winding or windings displaced in magnetic position from the main winding.

12. Split-phase reluctance motor.

The ASA does not define this type motor, but does define the reluctance type motor.

> A reluctance type motor is a synchronous motor similar in construction to an induction motor in which the member carrying the secondary circuit has salient poles without direct-current excitation. It starts as an induction motor but operates normally at synchronous speed (ASA 10.10.305).

From this definition, a split-phase reluctance motor may be described as a reluctance-type motor, the stator of which is exactly the same as in a split-phase induction motor, i.e., the stator has a main winding, an auxiliary winding and also a starting switch.

13. Capacitor-type reluctance motor.

From the ASA definition 10.10.305 given above, the capacitor-type reluctance motor is a reluctance type motor the stator of which may be wound in one of three ways discussed under definitions 4, 5, and 6, above, that is, as capacitor-start, as permanent-split capacitor, or as 2-value capacitor.

14. Capacitor-type hysteresis motor.

The ASA definition for the hysteresis motor is:

> A hysteresis motor is a synchronous motor without salient poles and without direct-current excitation, which starts by virtue of the hysteresis losses induced in its hardened steel secondary member by the revolving field of the primary and operates normally at synchronous speed due to the retentivity of the secondary core (ASA 10.10.315).

From this definition, a capacitor-type hysteresis motor may be described as a hysteresis-type motor with a stator winding which may be wound in one of the three ways described under 4, 5, and 6 above.

15. Shaded-pole hysteresis motor.

From ASA definition 10.10.315 given above, a shaded-pole hysteresis motor may be defined as a hysteresis-type motor with stator windings the same as in the shaded-pole motor defined under 11 above.

As can be seen from the definitions, the first 4 types of single-phase motors have, besides the main winding, an auxiliary winding for starting which is cut out when the motor has obtained a certain speed. The axes of both windings are displaced by half a pole pitch.

The permanent-split (or single-value) capacitor motor and the 2-value capacitor motor use the auxiliary winding not only for starting but also for running. These motors behave as imperfect 2-phase motors.

The rotor winding of the motor types 1 to 6 is of the squirrel-cage type.

The starting of the repulsion-type motors 7 to 9 is accomplished by a single stator winding with the aid of a d-c armature winding and a commutator in the rotor. While in the straight repulsion motor and in the repulsion-induction motor the commutator is used permanently, it is short-circuited at a certain speed in the repulsion-start induction motor.

Stator and rotor windings of the universal motor are similar to those of the d-c series motor. The stator winding is either concentrated and placed on salient poles (non-compensated universal motor) or distributed and placed in slots (compensated universal motor).

The stator windings of the shaded-pole motor are placed on salient poles. The short-circuited auxiliary winding consists of a single turn or coil placed around a portion of the main pole. The rotor winding is of the squirrel-cage type. The motor types 1 to 6, 8, and 11 are induction motors with constant-speed characteristics.

The reluctance motor (types 12 and 13) is a synchronous motor, the rotor of which has salient poles without direct-current excitation. The stator is similar to that of the induction motor.

The hysteresis motor (types 14 and 15) is a synchronous motor without salient poles and without direct-current excitation. The rotor contains a hardened steel ring and starts by virtue of hysteresis losses.

11-2. Stator Windings. Three types of windings are used for the stators of single-phase motors of the types 1 to 9 and 12 to 15. They are:

(a) Hand winding.

(b) Mould winding.

(c) Skein winding.

The following rule applies to all windings. The magnetic polarity must alternate from pole to pole (see Art. 11-4b), and, therefore, adjacent poles must be wound to give opposite polarity (exception see Art. 11-6a), i.e., if one pole is wound in a clockwise direction, the adjacent pole must be wound in a counter-clockwise direction.

(a) Hand winding. Consider Fig. 11-1 which shows the main winding of a 4-pole machine with 36 slots. It consists of 4 identical coil groups each of which contains 3 single coils. The winder starts with a single wire and winds first the inner coil 3-7, placing in the slots one turn at a time. When the inner coil is finished, he progresses to the next coil placed in the adjacent slots 2-8 and so forth. The end of the coil group lies in slot 9. From here the winder carries the wire to slot 16 and winds in the opposite direction all the turns of the coil 16-12. Then the coil 17-11 is wound and finally the last coil of this group, 18-10. The end of this group lies in slot 10. From here the winder carries the wire to slot 21 and so forth. All 4 coil groups are thus connected in series. For a parallel connection the winder stops after finishing coil 18-10 and starts coil 21-25 with a new wire.

Winding guides arranged to cover the sharp edges of the slots have to be used in order to protect the wire insulation from being scraped or damaged. Also, rods are to be provided which, inserted in the slots, keep the end connections from cov-

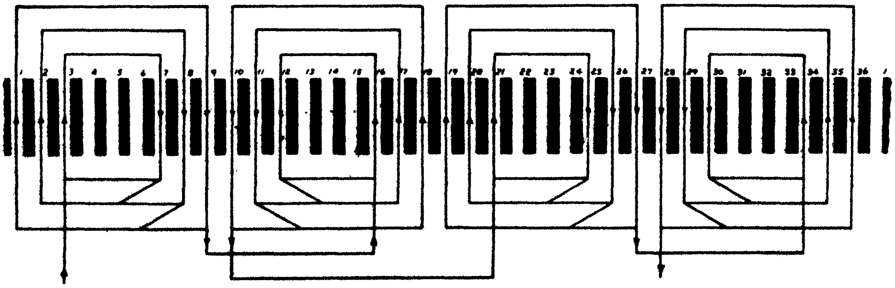


Fig. 11-1. Main Winding of a 4-pole stator with 36 slots. Hand winding.

ering up the unwound slots and provide space for the coils to be wound later.

(b) Mould winding. The concentric coils (see Fig. 1-6) are first wound on a mould and then placed into the slots by hand (Fig. 11-2). Using a stepped mould (Fig. 1-8), all the coils of a coil group can be made in succession with a single wire. Also it is possible to wind all the consecutive coil groups with a single wire. The latter may consist of one or two parallel strands. Instead of a mould, wire finishing nails driven into the bench can be used. In order to determine the perimeter of the mould or around the finishing nails, a single wire is looped around the stator teeth (in the center of the slot) in the same position in which the finished coil lies. As for the hand winding, guides to cover the sharp edges of the slots are necessary while feeding the wires into the slots. The end-extensions of the mould winding are usually somewhat larger than those of the hand winding. The single-phase mould winding also can be made

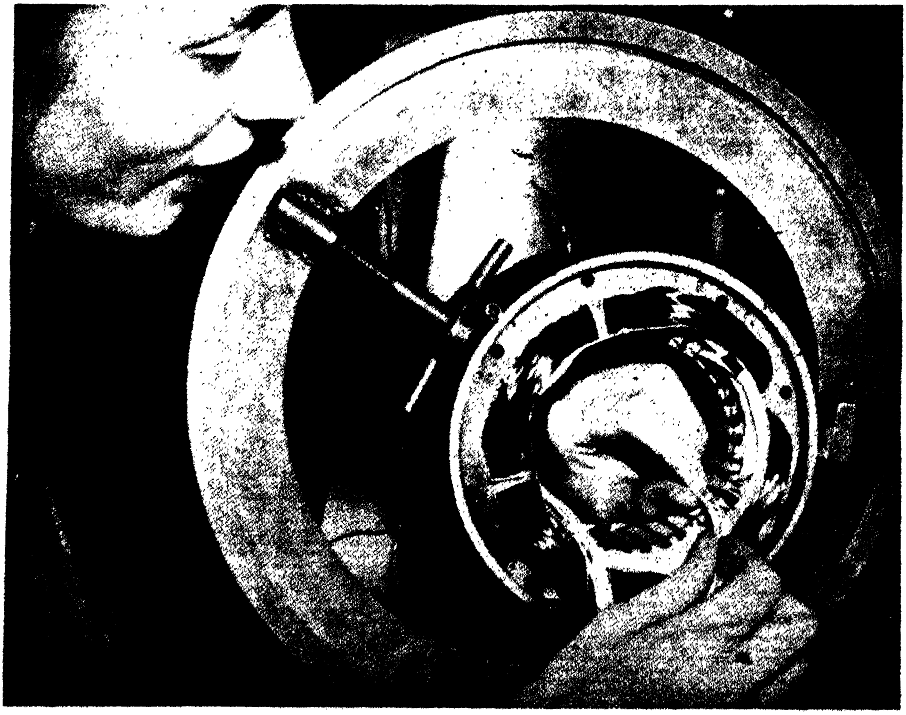


Fig. 11-2. Inserting a mould-formed winding into a 4-pole stator.

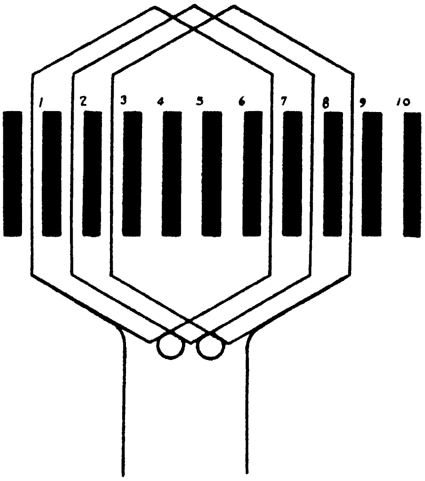


Fig. 11-3. Distributed windings for 1-pole group of a 4-pole stator with 36 slots.

as a distributed winding with equal coils similar to the distributed polyphase winding (Figs. 2-4 and 2-5). Fig. 11-3 shows one pole of the concentric winding shown in Fig. 11-1 wound in this way. The end-extensions and the weight of this winding are larger than those of the concentric mould winding. The mould winding is therefore preferred.

(c) Skein winding. The skein winding used often for auxiliary (starting) windings consists of as many skeins of wire as there are poles (Fig. 1-9). Each skein of wire is looped a number of times through the slots to form a pole.

The number of loops may be different in the individual slot pairs. The total number of turns per pole is equal to the number of turns in the skein times the number of loops.

Fig. 11-4 shows the steps necessary to put the skein into the slots of one pole of a 4-pole machine with 36 slots (see Fig. 11-1). The skein is placed into the slots 3 and 7 (Fig. 11-4a) a few wires at a time. Then the skein is pulled toward the winder, moving the end winding on the sides opposite to the leads close to the core. Care must be taken that the slot cells do not move together with the skein, otherwise the wire insulation may be scraped. In the next step, the skein is given half a turn (Fig. 11-4b), and the entire skein is passed through the stator core. Then the wires of slot 3 are fed into slot 8, and those of slot 7 are fed into slot 2 (Fig. 11-4c). After the end windings have been pulled tight to the core, the skein is given again half a turn, but in a direction opposite to the first twist (Fig. 11-4d), and the entire skein is passed through the stator core. The wires of slot 8 are now fed into slot 1, those of slot 2 are fed into slot 9, and the coil group is ready for shaping (Fig. 11-4e).

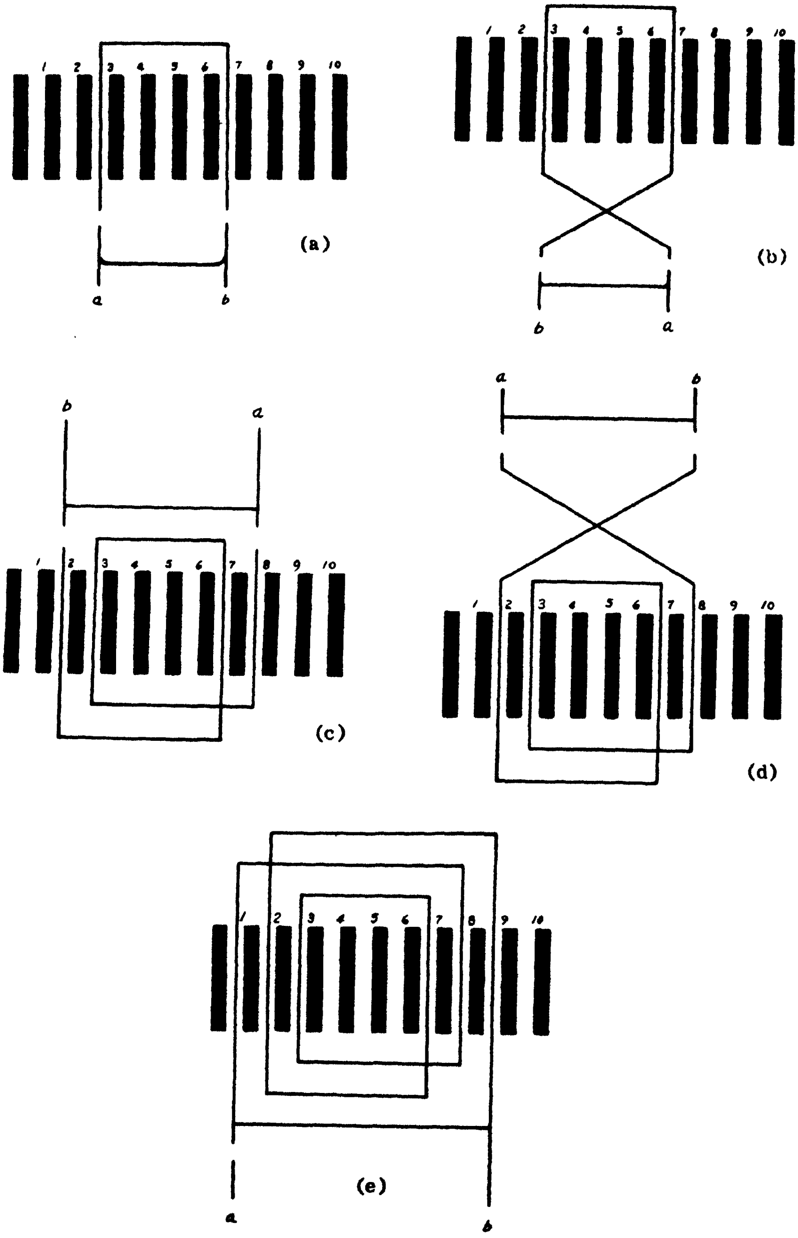


Fig. 11-4. Method of installing a skein winding by passing the entire skein through the core.

Note that in handling the skein care must be taken to avoid twisting and kinking of the wires. The half twist of the skein before passing it through the bore should be alternated in direction in order to avoid difficulty on the last part of the loop.

The skein winding becomes somewhat difficult to handle if the wire is larger than No. 20 or 21 and the weight of the skein is more than 2 or 3 ounces.

In order to determine the length of the skein, a single wire of No. 18 to 21 is looped in the slots (in their centers) in the same manner that the skein will be looped. Half of the total length of the wire is the approximate length of the skein. Now a trial skein can be made and wound in the slots. A correct length of the skein is important.

A skein can be made either by using an adjustable skein reel or by driving 2 nails, the skein length apart, in a board and winding the wire around the nails. The start and finish leads must be at the same end of the skein. Before removing the skein (by pulling one of the nails), short pieces of tape should be wrapped around the wires, at intervals, to avoid tangling of the wires and to separate both sides of the skein. These pieces of tape are removed as the skein is placed in the slots. When the skein is long, 4 instead of 2 nails can be used; the 2 middle nails prevent tangling of the wires.

In the method of making a skein winding described above, it is necessary to pass the entire skein through the core of the stator as many times as there are single coils minus one. Another method makes it unnecessary to pass the entire skein through the core. The principle of this method is to pass one side of the skein through the slots, by forming loops in it, until the last single coil is reached and then to use the other side of the skein for finishing the coil group. This is explained in Fig. 11-5 which shows one pole group, as in Fig. 11-4. In using this method, the lead end of the skein must be put in first and the leads should be made long enough so that they can be brought back to the front of the core through the last slots (1 and 9). In Fig. 11-5a a loop is made with the right-hand leg of the skein, passed into the stator core, and fed into the slots 2 and 8 (Fig. 11-5b). Then, since the last single coil is

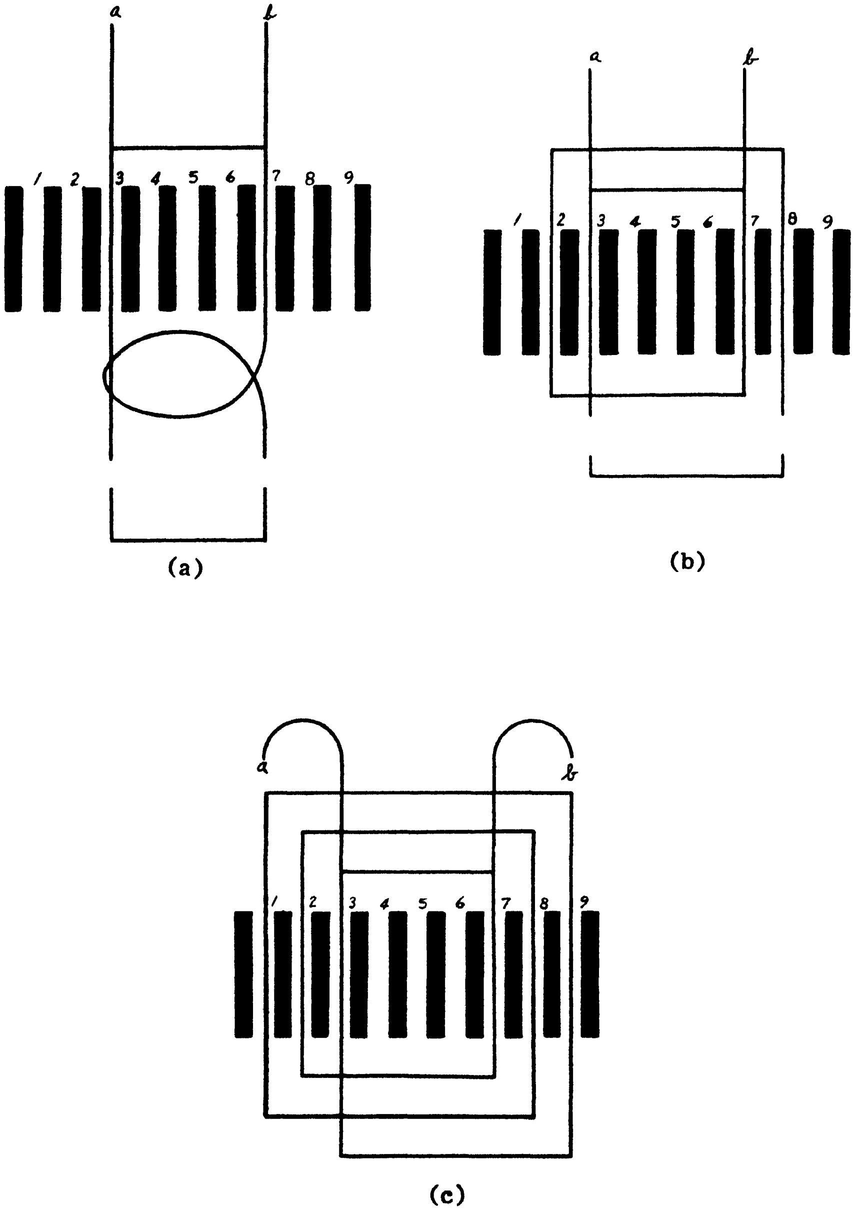


Fig. 11-5. Method of installing a skein winding by passing one side of the skein through the core.

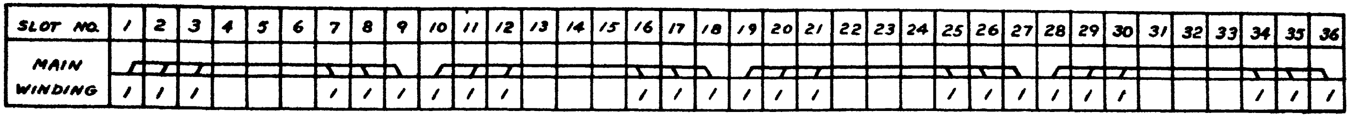
reached, the strands of the third coil are pulled over and fed into slot 9 and the rest of the coil fed into slot 1 (Fig. 11-5c). In general, the loops are all made by the same leg of the skein.

In Fig. 11-4 the number of loops is the same in all slots. The Distribution Chart (see Art. 11-4) of the main winding, corresponding to Fig. 11-4, is shown in Fig. 11-6.

The numbers in the squares indicate the number of times the loop passes through the slot. Another Distribution Chart for a similar 4-pole machine with 36 slots is shown in Fig. 11-7. In this case the skein of the main winding passes through most of the slots twice. The skein winding normally has as many coil groups as there are poles. The 4-pole winding shown in Fig. 11-1, which can be hand or mould wound, also has as many coil groups as there are poles (4). However, this latter winding can be wound with half as many coil groups. This is shown in Fig. 11-8. This 4-pole winding has only 2 coil groups. The essential part of a winding is the parts of the conductors which lie in the slots and not the end connections. It is important only that end connections do not connect conductors of the same polarity. Consider Fig. 11-1. The direction of the currents, if assumed arbitrarily for one of the 4 poles, is fixed for the other poles since it must alternate. Comparing Fig. 11-1 with Fig. 11-8, it is seen that in both cases the end connections connect only conductors of different polarities and both windings are therefore equivalent. The Distribution Chart corresponding to Fig. 11-8 is shown in Fig. 11-9.

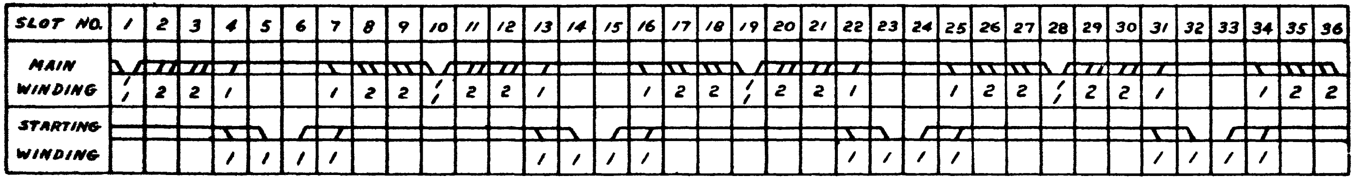
The arrangement shown by Fig. 11-1 with as many coil groups as there are poles is the normal one. The arrangement shown by Fig. 11-8 with half as many coil groups as there are poles is used in 2-speed motors (see Art. 11-6). In general, this type of winding is seldom used.

Apparently, end-connection arrangements other than those shown in Fig. 11-1 and 11-8 are possible without reducing the effectiveness of the winding. In Fig. 11-1, there are 4 coil groups with 3 single coils each; in Fig. 11-8 there are 2 coil groups with 6 single coils each. It is possible to make 2 coil groups with 4 single coils each and 2 coil groups with 2 single



SLOT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
MAIN WINDING	1	1	1				1	1	1	1	1	1				1	1	1	1	1	1				1	1	1	1	1	1				1	1	1

Fig. 11-6. Distribution chart of the main winding shown in Fig. 11-4.



SLOT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
MAIN WINDING	1 1	2	2	1			1	2	2	1 1	2	2	1			1	2	2	1 1	2	2	1			1	2	2	1 1	2	2	1			1	2	2
STARTING WINDING				1	1	1	1						1	1	1	1						1	1	1	1						1	1	1	1		

Fig. 11-7. Distribution chart of the main winding and the starting winding of a 4-pole winding in 36 slots.

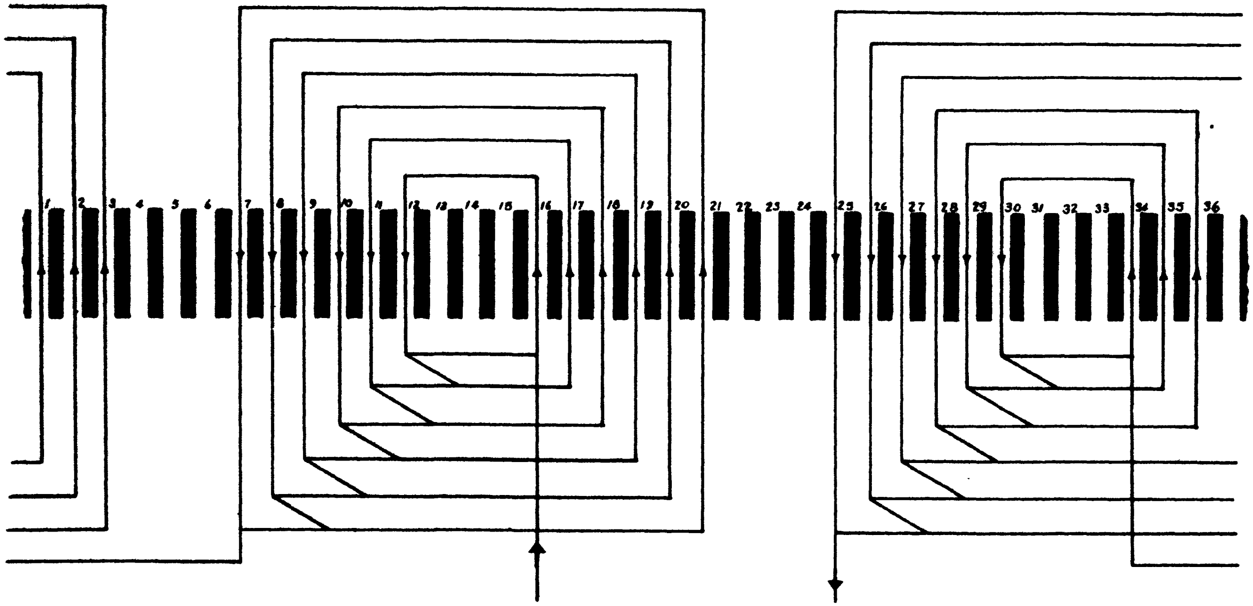


Fig. 11-8. Main winding of a 4-pole 36-slot stator with 2 coil groups. Each coil group has 6 coils.

coils each. Such windings with unequal coil groups are also used sometimes.

11-3. Insulation of the Wire and the Slots of the Stator. Single-cotton-covered enamel wire as well as plain enamel wire is used for the wire insulation of small single-phase motors. Where the space permits, the first type of insulation is preferable.

Up to 250 volts, a U-shaped rag-paper or fishpaper cell approximately 0.015 inches in thickness is used for slot (ground) insulation. The cell should be 1/4 to 3/8 inch longer than the width of the core. It should be cut so that the grain of the paper is parallel to the slot in order that it does not crack at the corners. The width of the cell must fit the contour of the slot; the cell should be neither too long and cover up a part of the slot opening, nor too short and make it possible for the wire to go between the cell and the tooth. After the slot has been completely wound, the edges of the slot cell are folded over each other and a wooden or fiber wedge is placed above the cell. The wedge should be 1/4 inch longer than the core. Fiber wedges can be cut from fiber sheet, approximately 1/16 inch thick.

A slot cell of higher mechanical strength is obtained when a fishpaper cell 0.007 inch thick is combined with a 0.007-inch treated-cloth cell. The fishpaper cell is put next to the iron. If the treated-cloth cell is made longer than the fishpaper cell so that it extends approximately 1/2 inch out through the slot opening, special guides to cover the sharp edges of the slots become unnecessary.

The combination cell of 0.007-inch fishpaper and 0.007-inch treated-cloth can also be used for voltages above 250 volts. However, in this case both cells must be cut to the same size as the plain rag-paper or fishpaper cell.

When the slot contains a main-winding coil and a starting-winding coil, both coil sides should be insulated from each other. For this purpose a thin strip of sheet fiber or fishpaper can be placed on the top of the first coil. When the combined cell is used, and the fishpaper cell is not attached to the treated-cloth cell, the latter can be used to give the in-

SLOT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
MAIN WINDING	1	1	1				1	1	1	1	1	1				1	1	1	1	1	1				1	1	1	1	1	1				1	1	1

Fig. 11-9. Distribution chart of the main winding shown by Fig. 11-8.

SLOT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	STRANDS PER COND.	WIRE SIZE GAUGE	INSUL.
MAIN WINDING	21	21	12	·	·	·	12	21	21	21	21	12	·	·	·	12	21	21	21	21	12	·	·	·	12	21	21	21	21	12	·	·	·	12	21	21	1	16	S.C.C. EN.
	21	21	12	·	·	·	12	21	21	21	21	12	·	·	·	12	21	21	21	21	12	·	·	·	12	21	21	21	21	12	·	·	·	12	21	21	1	16	S.C.C. EN.
STARTING WINDING	·	·	24	24	24 24	24	24	·	·	·	·	24	24	24 24	24	24	·	·	·	·	24	24	24 24	24	24	·	·	·	·	24	24	24 24	24	24	·	·	1	20	S.C.C. EN.

Fig. 11-10. Complete distribution chart of a 1/2-Hp, 4-pole, 36-slot capacitor-start motor. The main winding is wound in two parts for series or parallel connection.

sulation between the coil sides. It is to be cut off even with the slot opening and folded in the slot over the bottom coil. For the top coil side, an additional treated-cloth cell is to be put into the slot. After the top coil is wound, this cell is cut off even with the slot opening and folded. Then the fish-paper cell is folded and the wedge put into the slot.

The coil ends of the main and the auxiliary winding should be insulated from each other. For this purpose the coil ends of the auxiliary winding should be raised by a coil lifter and pieces of treated-cloth or rag-paper placed between the coil ends.

In a 2-pole motor, the depth of the core below the slots is greater than in a 4-pole or 6-pole motor of the same outside diameter, and therefore the coil ends are to be formed farther back than in the 4-pole or 6-pole motor. For this reason, it is safer to have fiber end-punchings on both ends of 2-pole stator cores. If in rewinding, the original end-punchings cannot be used, washers can be made from 1/32 to 1/16-inch fiber sheet and attached to the core ends by shellac or glue.

The coil ends after being formed to shape should be tied down solidly with tape or twine.

The stator with the complete winding should be dipped in insulating varnish and then baked from 4 to 12 hours at 200° to 250° F. If plain enameled wire is used, it is desirable to dip and bake the windings twice. When an oven for baking is not available, electric power can be used for this purpose. The main winding is connected to a low-voltage line so as to limit the current to a safe value and baked at a temperature of approximately 225° F. for 6 to 14 hours, depending on the size of the motor.

11-4. Different Types of Stator Diagrams. Several connection diagrams are necessary to give complete information about a winding. These diagrams are:

(a) The Distribution Chart. This gives the number of conductors in each slot for all windings, the number of coil sides in each slot, the size and insulation of the conductors, and the number of parallel strands per conductor. Figs. 11-6 and 11-7 are incomplete Distribution Charts. A complete Distribution

Chart of a 1/2-HP, 4-pole, capacitor-start motor for 60 cycles, 115/230 volts, with mould windings in 36 slots, is shown in Fig. 11-10. From this Distribution Chart one can see the following:

The main winding consists of 2 parts (to be connected in series for 230 volts or in parallel for 115 volts). Since the machine has 4 poles, each part of the winding consists of 4 pole groups. Each pole group has 3 coils. (The dots under the slot numbers indicate that for the particular winding the slots are empty, i.e., that this particular winding has no conductors in these slots.) The coil spans are indicated by a horizontal line with slant dashes. The coils with the smallest span lie in the slots 3-7, 12-16, and so forth, and have 12 conductors: the next wider coils lie in slots 2-8, 11-17, and so forth, and have 21 conductors, the coils with the largest span lie in the slots 1-9, 10-18, and so forth, and have 21 conductors. All conductors have one strand. Both parts of the main winding have size 16 wire. The insulation of the wires is single-cotton-covered enamel.

The starting winding also consists of 4 identical pole groups, each pole group having 3 coils with 24 conductors. The coils with the smallest span lie in the slots 7-12, 16-21, and so forth; the next wider coils lie in the slots 6-13, 15-22, and so forth; the coils with the largest span lie in the slots 5-14, 14-23, and so forth. The conductor of the starting winding consists of one strand of size 20 wire. The wire insulation is the same as for the main winding.

In skein windings, the number of slanting dashes pointing to a slot from the slot span line represents the number of times the skein goes through the particular slot (see Figs. 11-6 and 11-7).

The axes of the coils of the main winding (Fig. 11-10) go throuth slots 5, 14, 23, and 32. The axes of the coils of the starting winding go through the centers of the teeth between slots 9-10, 18-19, 27-28, and 36-1. The distance between the axes of both windings is 4.5 slot pitches. Since there are 9 slots per pole, the distance between the axes of both windings is equal to half a pole pitch, as it should be.

(b) Common Connection Diagrams. The Distribution Chart shows how to form the pole groups; the Connection Diagram shows how the pole groups must be connected in order to form both the main and auxiliary windings, respectively. Consider, for example, Fig. 11-13 which shows the Connection Diagram of a 4-pole winding with both windings in series. Each pole group is represented by an arc. Therefore, both windings are represented by 4 arcs each. In this Figure, as in all Connection Diagrams of this chapter, the outer winding is the main winding, the inner one the auxiliary winding. Following the rule that the magnetic polarity of a winding should alternate from pole to pole around the circumference, the end of the first pole group, (1) is connected with the end of the next following pole group, (2); the beginning of this pole group is connected with the beginning of the following pole group, (3), and so forth. This applies to both windings. In each winding, all 4 pole groups are connected in series. Corresponding to the Nema Standards as well as those of the American Standards Association, the terminals of the main winding are marked by T_1 and T_4, those of the starting winding by T_5 and T_8. The starting switch is placed in the lead T_5 of the starting winding.

The terminal markings according to the old Nema Standards as well as those of the American Standards Association were T_1 and T_3 for the main winding and T_2 and T_4 for the auxiliary or starting winding. The new markings are used throughout the chapter except in those cases where no new standards have been defined. In these cases (Figs. 11-33, 11-34, 11-37, 11-38, and 11-39) the old markings have been retained. The connection of the pole groups shown in the center of the Connection Diagrams refers to the main winding only.

In Fig. 11-14 which also shows the Connection Diagram of a 4-pole winding, the main winding is connected in parallel, the auxiliary winding in series. The auxiliary winding is, therefore, exactly the same as in Fig. 11-13. In the main winding, pole group 1 is connected in series with pole group 2, pole group 3 is connected in series with pole group 4, and both circuits are connected in parallel having common leads T_1 and T_4. Note that there is a cross-connection (equalizing connection) between the middle points of both parallel circuits, and that

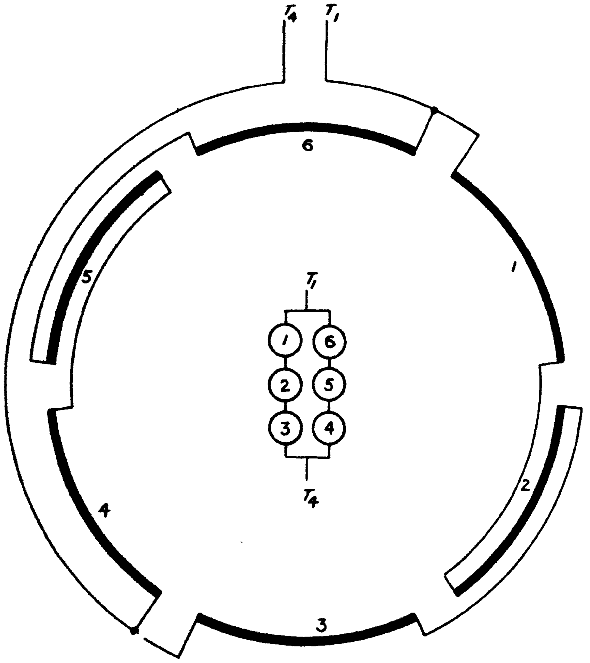


Fig. 11-25a. Main winding for 6 poles, connected in 2 parallel paths, without cross connections. Pole groups 1, 2, 3, and pole groups 4, 5, 6, are connected in series and both parts are connected in parallel.

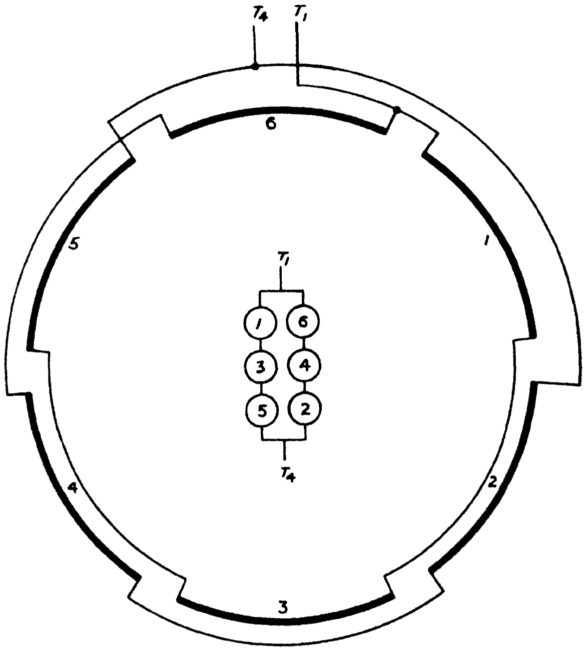


Fig. 11-25b. Main winding for 6 poles, connected in 2 parallel paths, without cross connections. Pole groups of same polarity are connected in series and both parts are connected in parallel.

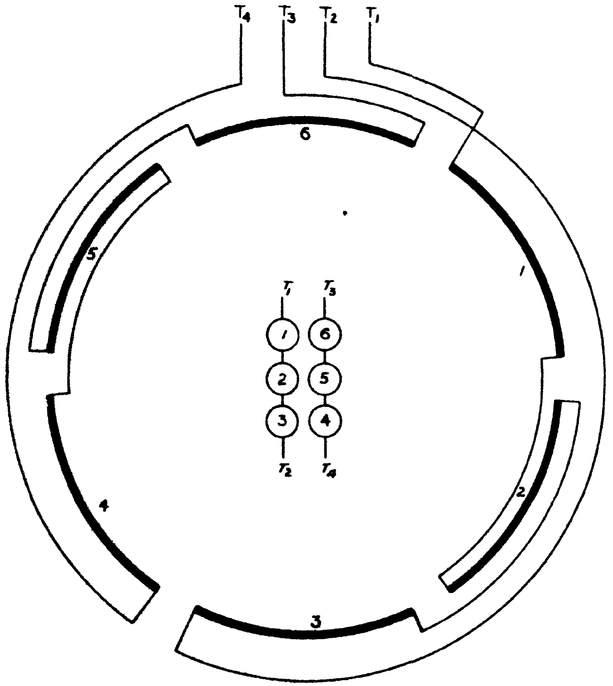


Fig. 11-25c. Main winding for 6 poles arranged for dual voltage operation. Pole groups 1, 2, 3, are connected in series and form one section of the winding;pole groups 4, 5, 6, are connected in series and form the second section of the winding.

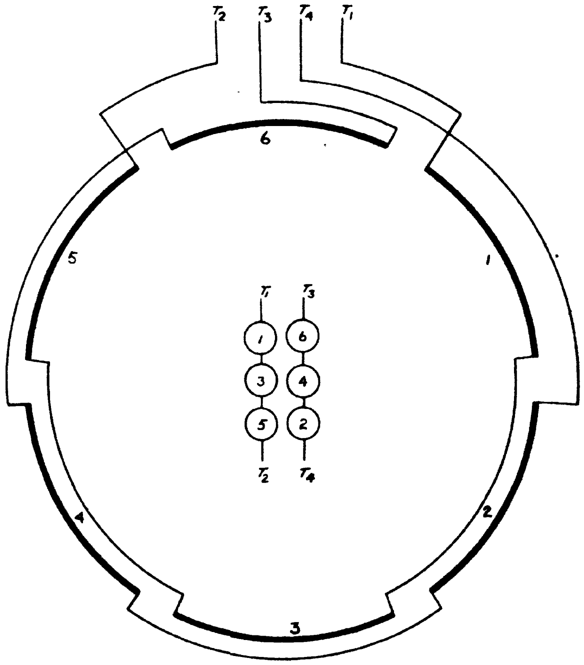


Fig. 11-25d. Main winding for 6 poles arranged for dual voltage operation. Pole groups 1, 3, 5, are connected in series and form one section of the winding;pole groups 2, 4, 6, are connected in series and form the second section of the winding.

diametrically opposite poles (1 and 3, 2 and 4) are connected in parallel. The purpose of this kind of connection is to equalize the flux in opposing poles and thus to reduce any unbalanced magnetic pull which may cause vibration and noise.

When both windings are connected in parallel, the auxiliary winding must be connected in the same manner as the main winding. Figs. 11-11 to 11-24 given at the end of the chapter show common Connection Diagrams. Guided by these, the repairman will be able to readily draw similar diagrams.

Where parallel connections of a winding have been made, diametrically opposite poles have been connected in parallel by cross-connections.

Fig. 11-25a shows another kind of parallel connection on a 6-pole winding, as an example. In this case, 3 adjacent pole groups (1, 2, 3, and 6, 5, 4) are connected in series and both circuits are connected in parallel without equalizing connections.

Another way of paralleling a winding is shown in Fig. 11-25b, again on a 6-pole winding, as an example. The winding consists of 2 sections, one of which contains all the pole groups of one magnetic polarity connected in series; while the other contains all the pole groups of the opposite magnetic polarity, also connected in series.

Compare Fig. 11-16 with Fig. 11-25b or Fig. 11-26, the latter of which represents a Connection Diagram for a 6-pole winding connected in series. In the first case adjacent poles are directly connected in series. In the second case alternate poles are connected with each other. Following the rule that alternate poles must have same polarity, the end of the first pole group is connected with the beginning of the third pole group and so forth. The first kind of connection (Fig. 11-16) is the usual one and is called the short-throw connection; the second kind is called the long-throw connection.

The windings of Fig. 11-25a and 11-25b can be arranged for dual-voltage operation if each winding part is brought out to terminals as shown in Fig. 11-25c and 11-25d respectively. Most dual-voltage motors of split-phase or repulsion types are connected according to Fig. 11-25d. For dual-voltage operation,

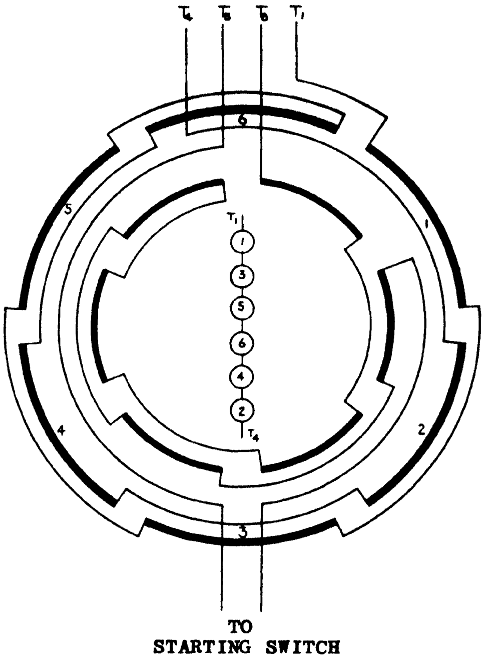


Fig. 11-26. Connection Diagram for 6 poles, both windings connected in series. Main winding connected by long throw connection.

the winding parts are to be connected as per line Connection Diagram Fig. 11-32b. (See also Art. 11-5.)

The resistance-start motor has a resistance in series with the starting switch. The capacitor-start motor has a capacitor in series with the starting switch. In the permanent-split capacitor motor no starting switch is used and the switch leads are connected to the capacitor.

The Connection Diagrams Figs. 11-11 to 11-24 have 4 leads, as is necessary for reversible motors. If only one definite direction of rotation is needed, the 4 leads T_1, T_4, T_5 and T_8 can be connected by pairs inside of the machine and only 2 leads brought out. It is shown below (See Fig. 11-28) that for counter-clockwise rotation T_1 is to be connected with T_5, and T_4 with T_8, while for clockwise rotation T_1 is to be connected with T_8, and T_4 with T_5.

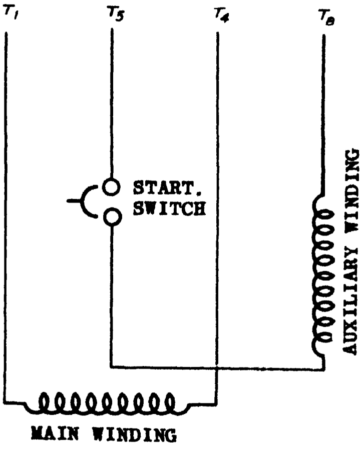


Fig. 11-27. Wiring Diagram of a plain reversible split phase motor with 4 leads.

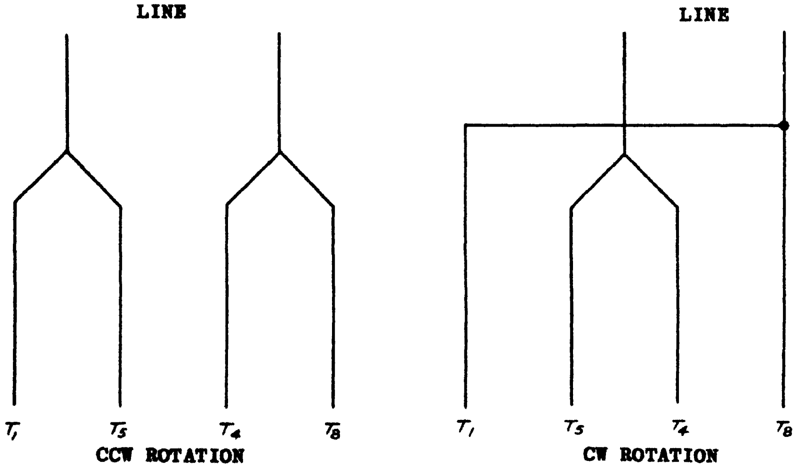


Fig. 11-28. Line-connection Diagram to Fig. 11-27 with connections for cw and ccw rotation.

(c) Wiring Diagram and Line-connection Diagram. The Wiring Diagram shows the internal connections of all windings to one another and also the connections of the windings to auxiliary devices such as a starting switch, resistor, reactor, capacitor, or thermal protective device. If no leads other than those shown in the Connection Diagram are necessary, a Wiring Diagram is superfluous.

The Line-connection Diagram shows the connections of the motor leads to the line. If there are only 2 line leads, a Line-connection Diagram is not needed.

Figs. 11-27 to 11-32 show common Wiring and Line-connection Diagrams for the different kinds of motors.

Fig. 11-27 is the Wiring Diagram of a plain reversible split-phase motor. The Line-connection Diagram, Fig. 11-28, shows the connection to the line for counter-clockwise rotation as well as for clockwise rotation. The Standards (ASA and Nema) specify the direction of rotation when looking at the machine from the front end which is defined as the end opposite the shaft extension. The direction of rotation given in Fig. 11-28 is true only if the leads are tagged in accordance with the Connection Diagrams, Figs. 11-11 to 11-24, and if the direction of rotation is specified from the connection end which is usually the front end of the motor. If the connections are made on the shaft-extension end of the motor, tags T_1 and T_4 are to be interchanged in the Connection Diagram, in order that the direction of rotation will agree with Fig. 11-28 and the Standards. It will be explained later (See Art. 11-8) how to determine the direction of rotation by test or by inspection of the stator connection diagram.

In the Wiring Diagram of the reactor-start, split-phase motor, Fig. 11-29, the starting switch opens the starting winding and at the same time eliminates the reactor in the main winding circuit.

Fig. 11-30 shows the Wiring Diagram for the reversible capacitor-start motor. The capacitor can be built into or mounted on the motor. The Line-connection Diagram is given in Fig. 11-28. The swing connection makes it possible to build an externally reversible capacitor-start motor with 3 line leads

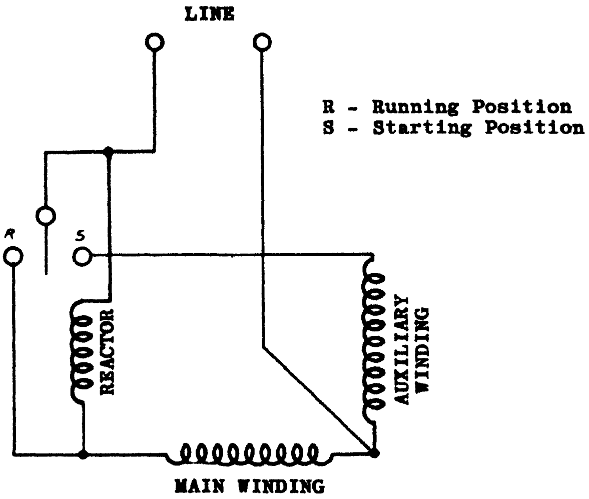


Fig. 11-29. Wiring Diagram of a non-reversible, reactor-start, split-phase motor with 2 leads.

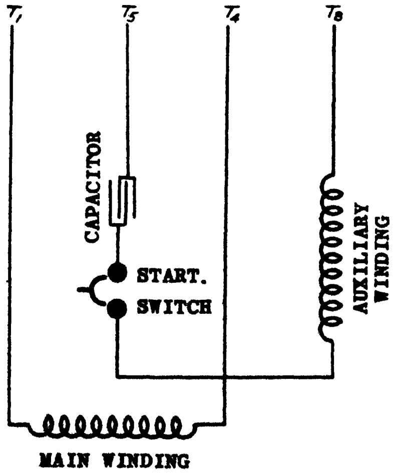


Fig. 11-30. Wiring Diagram of a reversible, capacitor-start motor with 4 leads.

instead of 4. For this purpose the main winding is arranged in 2 sections, in the way explained in the next article, and both sections are connected in series. One end of the auxiliary winding is connected to the mid-point of the main winding, the other end to the end-point of one or the other section, depending on the direction of rotation. The swing connection is used mainly for 230 volts.

The Wiring Diagrams, Figs. 11-31a and 11-31b, refer to the 2-value capacitor motor with 2 values of capacitance, one for starting, the other for running. The change in the value of capacitance is automatic and is effected either by an auto-transformer (Fig. 11-31a) or by 2 separate capacitors (Fig. 11-31b). The Line-connection Diagram is given in Fig. 11-28.

The Wiring and Line-connection Diagrams of the permanent-split (single-value) capacitor motor are identical with those of the capacitor-start motor (Fig. 11-30) except that the starting switch is omitted.

11-5. Dual-voltage Motors. In order that a motor be able to operate at 2 different voltages, for example at 230 and 115 volts, at least its main winding must consist of 2 sections. For the higher voltage (230 volts) both sections are connected in series; for the lower voltage (115 volts) they are connected in parallel.

Two different ways of making 2 winding sections were shown above in Figs. 11-25c and 11-25d. In Fig. 11-25d all pole groups of the same magnetic polarity are connected in series so that each section contains alternate pole groups. There are 2 more ways to produce 2 winding sections. One of them is to wind section 1 in the bottom of the slots, one pole group for every pole, just as a normal series winding is wound. Then section 2 is wound above section 1, in the same way and with the same number of turns. With the auxiliary winding above the second section, this results in a 3-layer winding. The second way is to wind 2 conductors in parallel from 2 spools of wire, one for each winding section. When the motor is operated at the higher voltage (230 volts), half or even more than half of this voltage will be between adjacent strands. Well-insulated wire is to be used in this case.

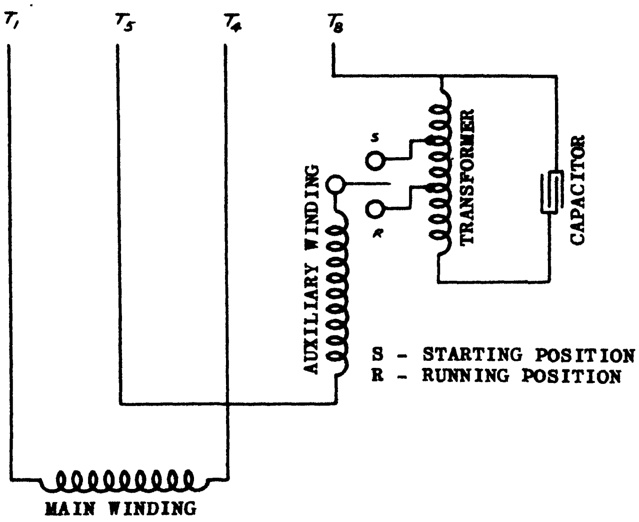


Fig. 11-31a. Wiring Diagram of a reversible, 2-value capacitor motor with transformer unit.

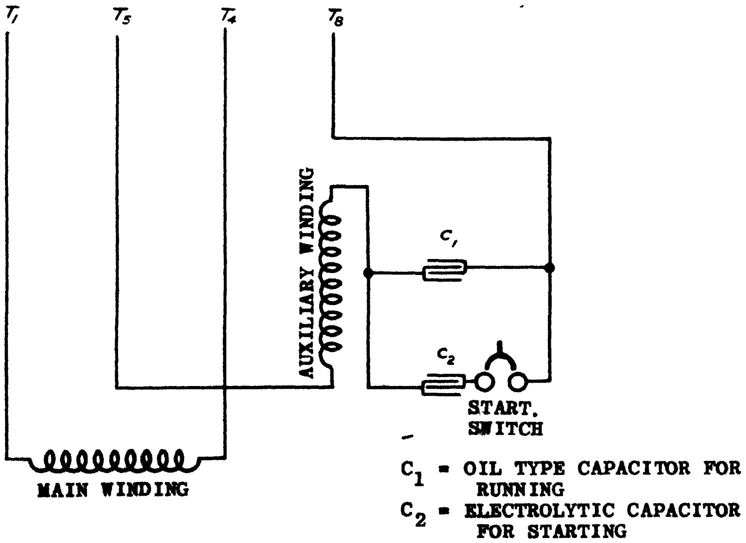

T_1
T_5
T_4
T_8
AUXILIARY WINDING
C_1
C_2
START. SWITCH
MAIN WINDING
C_1 = OIL TYPE CAPACITOR FOR RUNNING
C_2 = ELECTROLYTIC CAPACITOR FOR STARTING

Fig. 11-31b. Wiring Diagram of a reversible, 2-value capacitor motor with 2 capacitors.

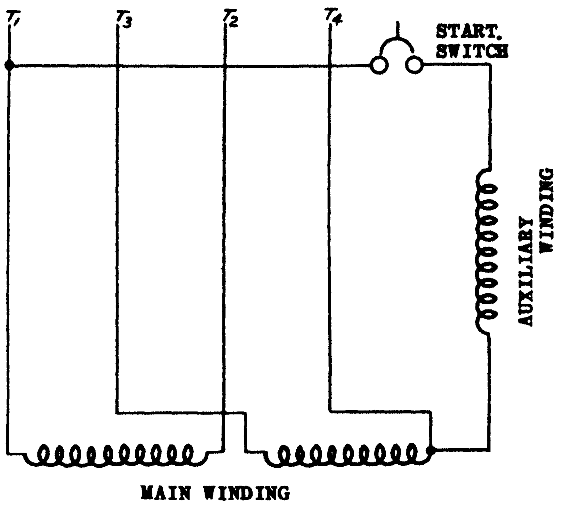


Fig. 11-32a. Wiring Diagram of a non-reversible dual-voltage, split-phase motor.

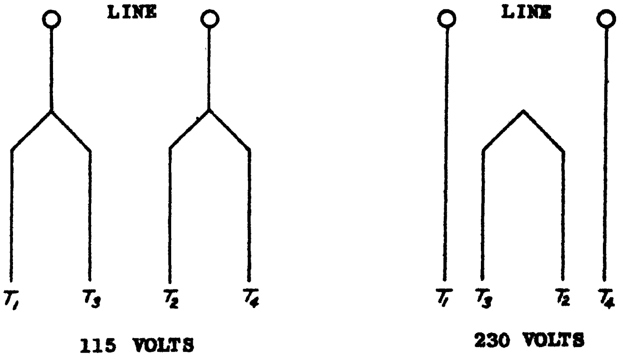


Fig. 11-32b. Line-connection Diagram to Fig. 11-32a.

Most dual-voltage split-phase motors are connected either according to Fig. 11-25d or as the 3-layer arrangement. In dual-voltage capacitor motors (of all types), the 3-layer arrangement or the 2 parallel wires are mostly used. In dual-voltage repulsion motors, the connection according to Fig. 11-25d is the more common.

Figs. 11-32a and 11-32b show the Wiring and Line-connection Diagrams of a dual-voltage, split-phase motor. The main winding is connected according to Fig. 11-25d, namely in series for 230 volts and in parallel for 115 volts. The starting winding is connected directly to the line. When the motor is operated at the lower voltage (115 volts), the starting torque is only about half as large as that at the higher voltage. This arrangement is therefore used when the motor is of the clutch type or where it drives a fan or blower.

The starting winding can also be connected in parallel to one section of the main winding. In this case, the starting torque is the same at both voltages, and the 3-layer arrangement of the main winding is preferred.

Non-reversible, dual-voltage capacitor motors usually have the starting winding parallel to one section of the main winding and the main winding is either of the 3-layer or 2-parallel wire type.

11-6. Two-speed Motors. Three different methods can be used to change the speed of a single-phase motor. One consists of arranging in the stator 2 complete sets of windings, each for a different number of poles. According to Eq. 1-1, 2 different speeds are then obtained for the same line frequency. The other 2 methods consist of changing the line voltage or in changing the number of turns of the main winding by tapping it.

The 2-winding-set method is mostly used in split-phase and capacitor-start motors; the voltage change and tapped-winding methods are mostly used in permanent-split capacitor motors. The tapped-winding is seldom used.

(a) Two-speed motors with 2 winding sets. The arrangement of the 2-winding sets, i.e., of the 2 main windings and 2 auxiliary windings requires considerable space. In order to facilitate winding, the so-called consequent-pole connection is often used for the auxiliary or low-speed windings (See Art. 11-2). This connection has fewer coil groups than there are poles.

Fig. 11-33 shows a Connection Diagram for 4-6 poles (1725-1140 rpm at 60 cycles). The outer winding is the 4-pole main winding. The next is the 6-pole main winding. The third is the 4-pole auxiliary winding arranged as a consequent-pole winding with 2 coil groups only. The extreme inner winding is the 6-pole auxiliary winding with 2 coil groups only.

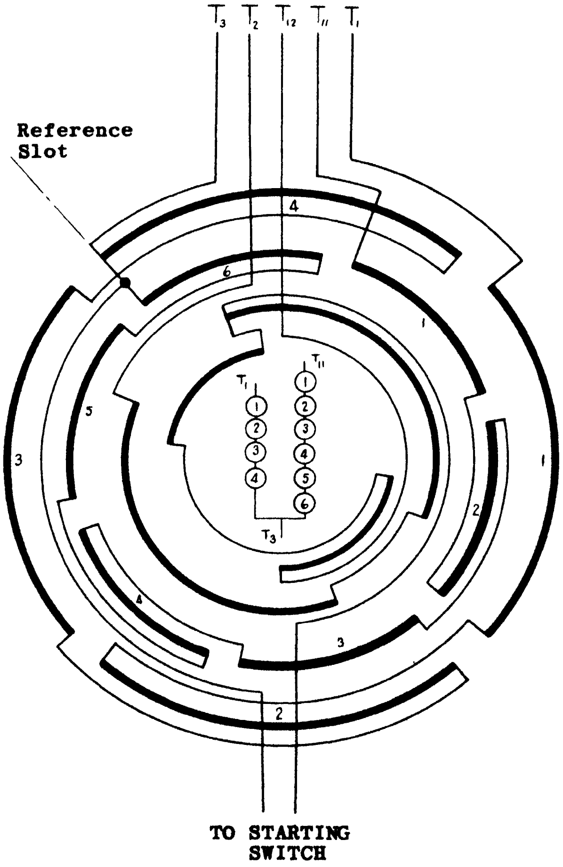


Fig. 11-33. Connection Diagram for a 2-speed (4-6 poles) motor. The outer winding is the 4-pole main winding. The next is the 6-pole main winding. The third is the 4-pole auxiliary winding arranged as a consequent-pole winding with 2 coil groups only. The extreme inner winding is the 6-pole auxiliary winding with 2 coil groups only.

In Fig. 11-33, both auxiliary windings are of the consequent-pole type. It is also possible to make the main winding of this type. Two examples will be given. A stator winding for 4-8 poles may have the 4-pole main winding normal and the 3 other windings of consequent-pole type, i.e., the 8-pole main winding having 4 coil groups, the 4-pole auxiliary winding having 2 coil groups, and the 8-pole auxiliary winding having 4 coil groups. A stator winding for 6-8 poles may have the 6-pole main winding normal, the two 8-pole windings of consequent-pole type, i.e., the 8-pole main winding and the 8-pole auxiliary winding with 4 pole-groups each, and the 6-pole auxiliary winding with 2 coil groups, as shown in Fig. 11-33. The 6-pole auxiliary winding can also be made of the normal type, i.e., with 6 coil groups.

Fig. 11-34 shows the Wiring and Line-connection Diagram of a 2-speed, 2-winding, split-phase motor. The connections are so arranged that only one starting switch is necessary. This starting switch must operate at 75 to 80% of the synchronous speed of the low-speed winding.

When the arrangement shown in Fig. 11-34 is applied to a capacitor-start motor, either one capacitor can be used in series with the starting switch, or 2 capacitors can be used, one connected in series with the T_2 lead and the other in series with T_{12} lead.

If it is permissible to start always on the same speed connection, one of the auxiliary windings can be omitted. The starting is, in this case, either semi- or full-automatic.

(b) Two-speed motors with tapped windings. It has been mentioned that the speed of a single-phase motor can be changed by varying its voltage or by changing the number of turns of its main winding. The first method makes an auto-transformer necessary and is used mainly in permanent-split capacitor motors for shaft-mounted fans and blowers. More than 2 speeds can be achieved with the auto-transformer.

The change in the number of turns of the main winding is achieved by tapping it. The stator then has 3 windings: the main winding, an intermediate winding, and the auxiliary winding. The first 2 windings have the same magnetic axis, i.e., the intermediate winding is wound in the same slots as the main winding

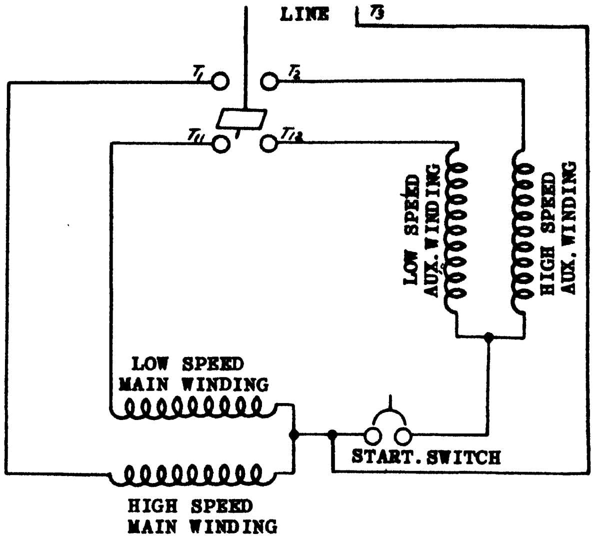


Fig. 11-34. Wiring and Line-connection Diagram for a 2-speed, 2-winding, split-phase motor.

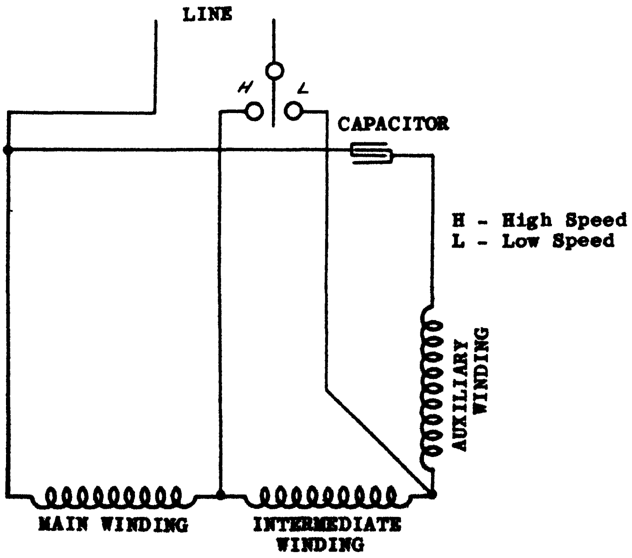


Fig. 11-35. Schematic L connection of the 3 windings of a 2-speed motor.

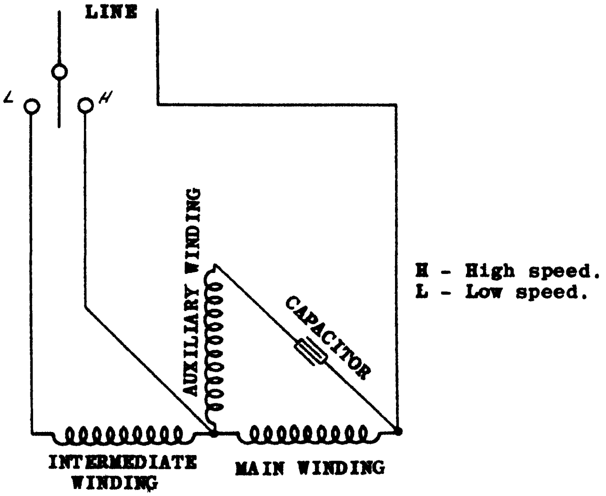


Fig. 11-36. Schematic T connection of the 3 windings of a 2-speed motor.

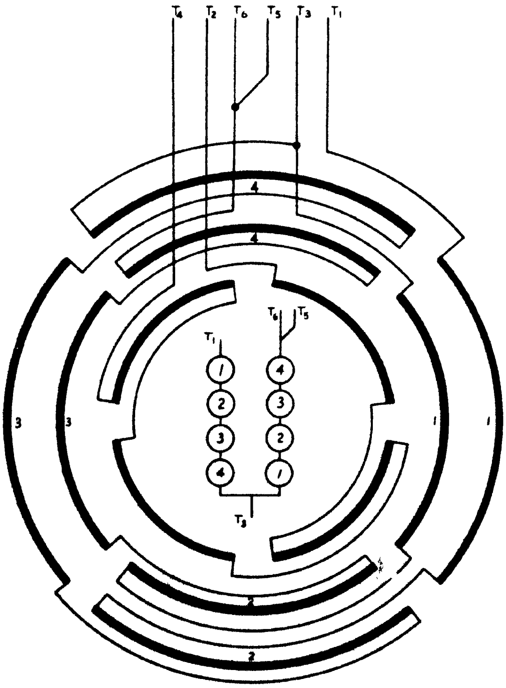


Fig. 11-37. Connection Diagram for a 2-speed, 4-pole motor with L connection. All windings connected in series.

(on top of it). The 2 common methods of connecting the 3 windings are the L and T connections. Schematic diagrams of these two connections are shown in Figs. 11-35 and 11-36. The L-connection is used mainly for 115-volt motors, whereas the T-connection is used mainly for 230-volt motors. In both cases the capacitor element is then operated at about 300 volts. If the L-connection is used for a 230-volt motor, the capacitor element is operated at about 500 volts.

Fig. 11-37 shows the Connection Diagram for a 4-pole, L-connection with all 3 windings in series. The Connection Diagrams for 6, 8, and 10 poles, with the L-connection and all windings in series, are the same as Fig. 11-37, except that the number of pole groups in each of the 3 windings is 6,or 8,or 10, respectively. Fig. 11-38 shows the Wiring and Line-connection Diagram for Fig. 11-37. Fig. 11-39 shows a Connection Diagram for 6 poles with L-connection in which the main and auxiliary windings are connected in parallel and the intermediate winding is connected in series.

For the T-connection, the same Connection Diagrams (Figs. 11-37 and 11-39) can be used except that T_6 is to be internally connected with T_3 instead of T_5.

11-7. Repulsion-type Motors.

The repulsion-type motors start with the aid of a d-c armature winding in the rotor in connection with a commutator and brushes. Therefore, they do not need a starting winding. The stator winding is usually hand-wound or mould-wound with concentric or distributed coils (Figs. 11-1 and 11-3). Some of the stator slots are partially filled. The stator Connection Diagrams are the same as for the main winding of the single-phase motors treated above. When used for a single voltage, the Connection Diagrams of the main winding of Figs. 11-11 to 11-24 can be applied. When used for 2 parallel circuits, the Connection Diagram of the type shown by Fig. 11-25b is often applied and, for dual-voltage motors, the corresponding Connection Diagram of the type shown in Fig. 11-25d is most commonly applied. In both cases, alternate pole groups are connected in series for each path or section of the winding.

The Wiring and Line-connection Diagrams of a dual-voltage repulsion-type motor are the same as for the split-phase motor

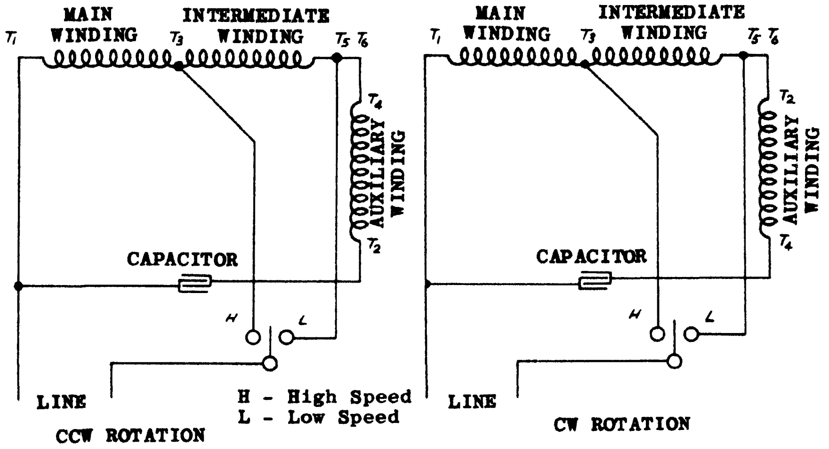


Fig. 11-38. Wiring and Line-connection Diagram to Fig. 11-37.

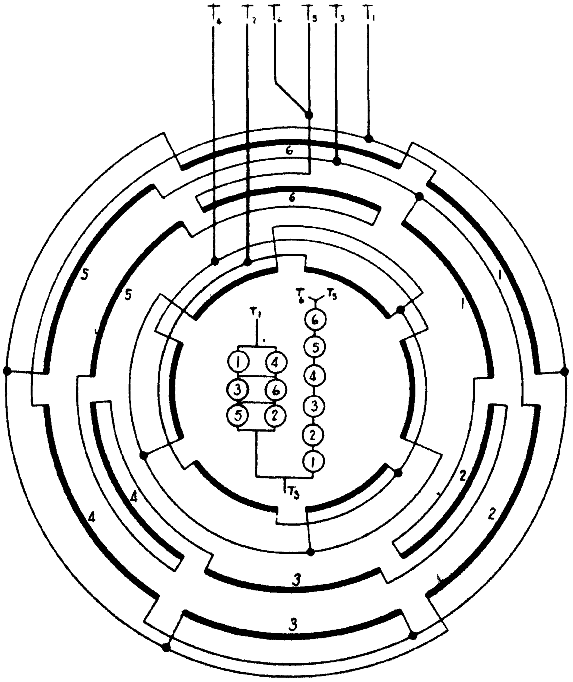


Fig. 11-39. Connection Diagram for a 2-speed, 6-pole motor with L connection. Main and auxiliary windings are connected in 2 parallel paths, intermediate winding connected in series.

(Figs. 11-32a and 11-32b), except that the auxiliary winding and starting switch are not present.

11-8. Pre-determining the Direction of Rotation and Reversing of Split-phase Type Motors. It should be noted first that the direction of rotation of the rotor of a split-phase type motor is always from an auxiliary winding pole of certain polarity to the nearest main winding pole of the same polarity. On this basis the following 2 methods can be applied in order to pre-determine the direction of rotation using only the stator. The first method uses a test, the second an inspection of the Connection Diagram of the stator windings.

(a) Short-circuit the 2 starting switch leads, join the main and auxiliary windings, and excite the 2 line leads with alternating current. Suspend now a piece of soft iron wire, about 1 to 1 1/2 inches long, on the end of a thread in the stator bore and open the starting switch leads; the wire will then move in the direction of rotation. If 60 cycles are used for excitation of the windings, not more than half voltage should be applied. If a larger or smaller frequency is used, the applied voltage can be proportionally larger or smaller. The suspended wire should not touch the stator iron. If the current in the windings is too large, it is better to suspend the wire outside of the stator iron, above the end-windings.

(b) Consider the Connection Diagram, Fig. 11-13. Let T_1 be connected to T_5 and assume that the current flows from the line through T_1 and T_5 into both windings. Then the current in the first pole group of the main winding flows clockwise. The current flowing from T_5 through the starting switch also passes clockwise through the first pole group of the auxiliary winding. Thus, the first pole groups of both windings have the same magnetic polarity and the direction of rotation will be counter-clockwise, since the rotation is always from an auxiliary winding pole toward the nearest main winding pole of the same polarity. If T_1 is connected with T_8 (instead of T_5), the direction of rotation is clockwise. Note that the assumption of the direction of the line current has no influence on the results obtained.

It follows from the foregoing that, in order to reverse the single-phase type motor, the direction of current in the auxiliary winding, with respect to that of the main winding, must be reversed. Thus, if in Fig. 11-14, as an example, T_1 is connected with T_5, and T_4 with T_8, the direction of rotation is counterclockwise and, if T_1 is connected with T_8, and T_4 with T_5, the direction of rotation is clockwise (See Fig. 11-28). Note that the direction of rotation is specified from the connection end (See Art. 11-4c).

11-9. Reconnecting or Rewinding a Split-phase Motor for a Different Voltage at the Same Performance.

If a split-phase motor is to be changed from 230 to 115 volts and both windings are connected in series, both windings have to be reconnected in parallel. If the voltage is to be halved and both windings are connected in parallel, both windings have to be rewound with half as many turns and with twice the wire size of the original windings.

If the voltage is to be changed from 115 volts to 230 volts and both windings are connected in series, both windings are to be rewound with twice as many turns and with wire half the size of the original windings. If the voltage is to be changed from 115 to 230 volts and the main winding is connected in parallel, while the auxiliary winding is connected in series, the main winding is to be reconnected in series and the auxiliary winding is to be rewound with twice as many turns and with half the wire size. The auxiliary winding can be used, if the motor is rewound for dual voltage and the auxiliary winding is connected in parallel to one section of the main winding (See Art. 11-5). It is not safe to change a split-phase motor from 230 to 440 volts, because of possible difficulties with the starting-switch.

If the voltage is not to be halved or doubled but changed by a certain percentage, the necessary number of turns is given by Eq. 10-1. Since the performance is not to be changed, the flux per pole must remain the same as before, i.e., the number of turns is to be changed by the same percentage as the voltage is to be changed. Let V be the original voltage and V' the new voltage, then the number of turns of both, the main and auxiliary winding, must be

$$\frac{V'}{V} \times \text{No. turns in the old windings}$$

and the cross-sectional area of the wire should be

$$\frac{V}{V'} \times \text{Area of wire in the old windings}$$

or as near as possible to this value.

As a rule, the difference in the wire sizes between auxiliary and main windings is to be the same in the rewound motor as it was in the original motor. While rewinding, the area of the wire of the main winding should be made as large as possible, but this should not be done for the auxiliary winding.

11-10. Reconnecting or Rewinding a Capacitor-start motor for a Different Voltage at the Same Performance. If the capacitor-start motor is to be changed from 230 to 115 volts and both windings are connected in series, both windings are to be reconnected in parallel. The method of paralleling shown in Fig. 11-25d can be used, i.e., the winding is split into 2 sections, each including every alternate pole. If the voltage is to be halved and both windings are connected in parallel, both windings are to be rewound with half as many turns and with twice the wire size of the original windings. Whether reconnected or rewound, in both cases a 115-volt capacitor of 4 times the microfarad rating of the original 230-volt capacitor must be used. If the motor is swing-connected (Art. 11-4c) and the voltage is to be halved, only the 2 sections of the main winding are to be reconnected in parallel, while the auxiliary winding and capacitor remain unchanged. The motor is then non-reversible.

If the voltage is to be changed from 115 to 230 volts and both windings are connected in series, both windings are to be rewound with twice as many turns and half the wire size of the original windings and a 230-volt capacitor of 1/4 the microfarad rating of the 115-volt capacitor must be used. The original capacitor and auxiliary winding can be used if the motor is rewound for dual-voltage or the swing connection; in this case each section of the main winding must have the same number of turns as the 115-volt winding and a wire size half of the original. If the main winding is arranged in 2 parallel strands (See Art. 11-5) doubling of the voltage can be achieved by connecting the strands in series and using the swing connection. However, before connecting the strands in series, a test between the strands at 500 volts should be made.

If the voltage is to be doubled and both windings are connected in parallel, both windings are to be reconnected in series and a 230-volt capacitor of 1/4 the microfarad rating of the 115-volt capacitor used.

If the voltage is to be changed from 230 to 440 volts, only the dual-voltage or swing connection should be used, with consideration for the switch and the capacitor.

Halving and doubling the voltage were considered. For a general change of voltage, the same rules apply with respect to the number of turns of both windings and to the cross-sectional area of the wire as those given for the split-phase motor in the preceding article. The microfarad rating of the capacitor should be

$$\left(\frac{V}{V'}\right)^2 \times \text{Microfarad rating of the original capacitor}$$

11-11. Reconnecting or Rewinding a Permanent-split and a 2-Value Capacitor Motor for a Different Voltage at the Same Performance.

For the permanent-split capacitor motor the same rules apply as for the capacitor-start motor. A change of voltage of the 2-value capacitor motor involves a change of the capacitor-transformer unit (Fig. 11-31a) or of the double-unit capacitor (Fig. 11-31b). For this reason it is advisable to make only such changes of voltage which permit use of the original capacitor transformer unit or the double-unit capacitor. This is, for example, the case when a 2-value capacitor motor is to be rewound from 115 to 230 volts. Then the dual-voltage or the swing connection can be applied, and only the main winding is to be rewound. Each section of it must have the same number of turns as the 115-volt main winding with a wire one half the size of that of the original winding. The auxiliary winding and the capacitor-unit remain unchanged. If the main winding consists of 2 parallel strands per conductor, each strand can be used as a section. However, before connecting the sections in series the insulation between the strands should be tested at 500 volts.

If an L-connected, 2-speed, tapped-winding, permanent-split capacitor motor is to be changed from 115 to 230 volts, the following changes are necessary: the number of turns of the main and intermediate windings must be doubled and the wire used must be one half of the size of the original wire; the rewound motor should be T-connected. If the main winding is connected in parallel, it can be reconnected in series without rewinding.

If a T-connected, 2-speed, tapped-winding, permanent-split capacitor motor is to be changed from 230 to 115 volts, the following changes are necessary: the number of turns of main and intermediate windings must be halved and the wire used must be twice the size of the original wire; the rewound motor should be L-connected. If the main and intermediate windings are connected in series, they can be reconnected in parallel without rewinding.

11-12. Rewinding for a Different Breakdown Torque at the Same Voltage.

At a given voltage and frequency, the breakdown torque of the split-phase and capacitor-start motor varies approximately inversely as the square of the number of turns of the main winding. For example, in order to increase the breakdown torque by 20%, the number of turns of the main winding must be decreased 10%. However, since a change of the number of turns of the main winding changes the flux per pole (See Eq. 10-1) and the currents in the stator and rotor windings, the losses in the iron and in the copper which appear as heat will be changed. For this reason it is necessary to determine experimentally, before rewinding for a different breakdown torque, whether the total losses are considerably increased. The possibility of such a test is given by the fact that the breakdown torque is approximately proportional to the square of the line voltage. If, for example, the line voltage is increased by 10%, the breakdown torque will increase by 20%. Therefore, if an increase of the breakdown torque of 20% is desirable, the motor input is to be determined experimentally at 110% normal voltage. If this input is appreciably higher than that at normal voltage, a temperature run should be taken at operating load and 110% normal voltage. The ambient temperature and that of the winding at its hottest accessible spot should be measured after the winding temperature becomes constant. The temperature rise, i.e., the difference between the temperature of the winding and ambient, should not be over 40^{o} C, when the motor is open, and not over 55^{o} C, when the motor is totally closed.

If the breakdown torque of a capacitor-start motor is to be increased, it should be done in narrow limits, otherwise the life of the capacitor may be reduced. Two-value capacitor motors and permanent split capacitor motors should not be rewound by the serviceman for an increase in breakdown torque unless specifications from the manufacturer are available.

11-13. Rewinding for a Different Frequency.

The following rules apply to the split-phase motors only. It is not advisable for the serviceman to rewind a capacitor-type motor for another frequency without having specifications from the manufacturer.

If the frequency of a split-phase motor is to be changed from 50 to 60 cycles and the required torques are not too high, ordinarily it will be unnecessary to change either the windings or the switch. For a change from 60 to 50 cycles, no winding change is usually necessary for the general-purpose motor. However, it may be necessary to increase the number of turns by 10% in order to avoid overheating in the case of the high-torque motor. When a change from 60 to 50 cycles is made, the rotating member of the starting switch should be changed.

For larger changes of frequency than 50 to 60 cycles and vice versa, the number of turns of both windings must be changed and a starting switch that operates at the new speed is necessary.

11-14. Changing a Split-phase Motor to a Capacitor-start Motor.

The starting torque of a split-phase motor can be increased or its locked-rotor current can be reduced by inserting a (electrolytic) capacitor in the circuit of the auxiliary winding. With a proper capacitor the starting torque can be increased up to 100% and the starting current reduced down to 40%. The proper microfarads of the capacitor should be determined by test.

11-15. Changing a Capacitor-start Motor to a Split-phase Motor.

If a capacitor-start motor is to operate as a split-phase motor, usually a resistance will have to be substituted for the capacitor, otherwise the motor may not start. The resistance also reduces the locked-rotor current. The resistance for maximum starting torque should be determined by test. Normally an external resistance of one to two times the ohmic resistance of the auxiliary winding will yield maximum starting torque (See reference at the start of the chapter).

11-16. Changing a 2-Value Capacitor Motor with Transformer Unit to a Capacitor-start Motor. By substituting an electrolytic capacitor for the capacitor-transformer unit, a 2-value capacitor motor may be operated as a capacitor-start motor. The microfarads of the electrolytic capacitor can be approximated in the following way. Determine the turns ratio of the auto-transformer on the starting connection by measuring the voltages or by stripping the transformer coil and counting the turns. The micro-farads of the electrolytic capacitor should be about 80 to 90 per cent of

$$(\text{Turns ratio})^2 \times \text{Microfarads of the original capacitor.}$$

It should be noted that operating as a capacitor-start motor, the motor will have a 10% to 25% smaller breakdown torque and its full-load losses and therefore its heating will be increased. Furthermore, higher voltages may shorten the life of the electrolytic capacitor (see reference at the start of the chapter).

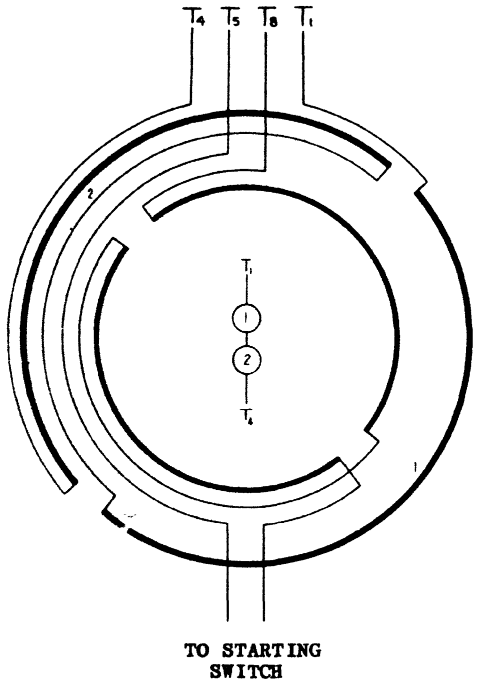


Fig. 11-11. Connection Diagram for 2 poles, main and auxiliary windings connected in series.

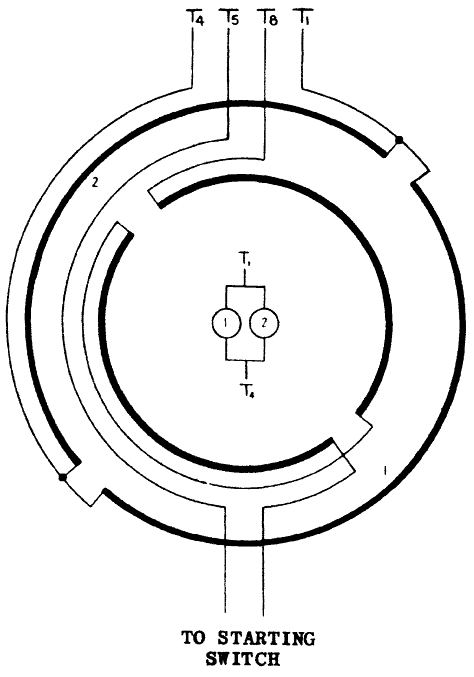


Fig. 11-12. Connection Diagram for 2 poles, main winding connected in 2 parallel paths, auxiliary winding connected in series.

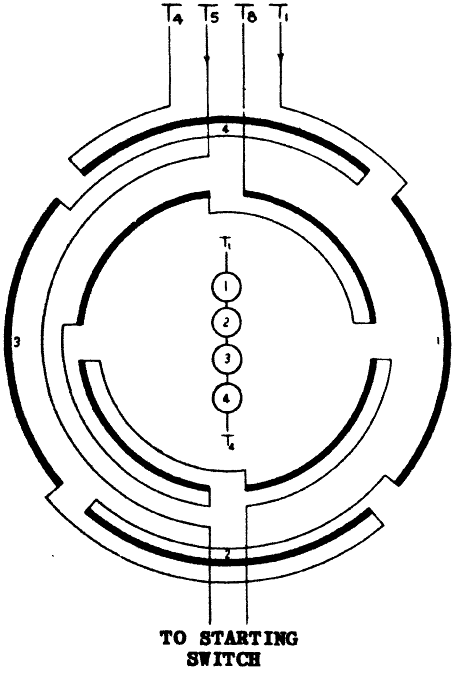


Fig. 11-13. Connection Diagram for 4 poles, both windings connected in series.

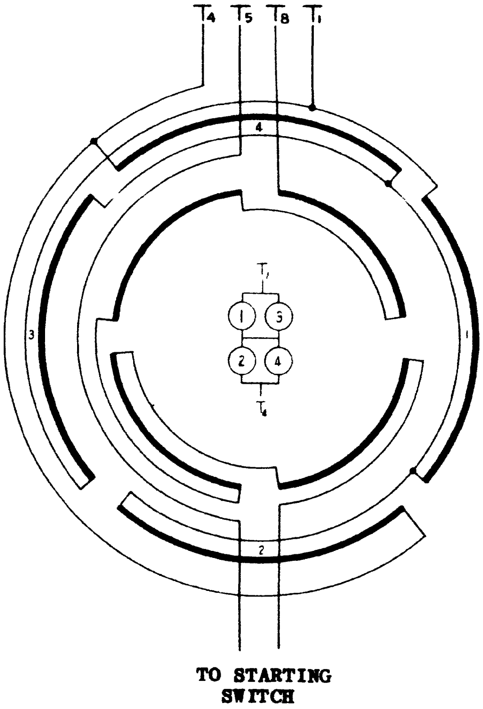


Fig. 11-14. Connection Diagram for 4 poles, main winding connected in 2 parallel paths, the auxiliary winding connected in series.

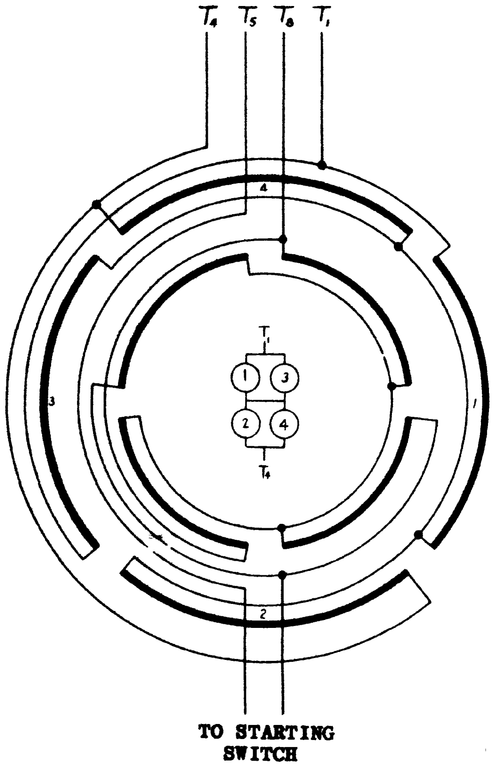


Fig. 11-15. Connection Diagram for 4 poles, both windings connected in 2 parallel paths.

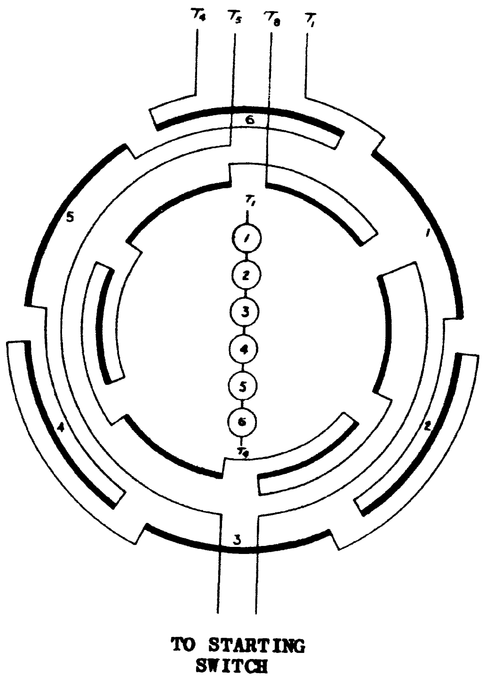


Fig. 11-16. Connection Diagram for 6 poles, both windings connected in series.

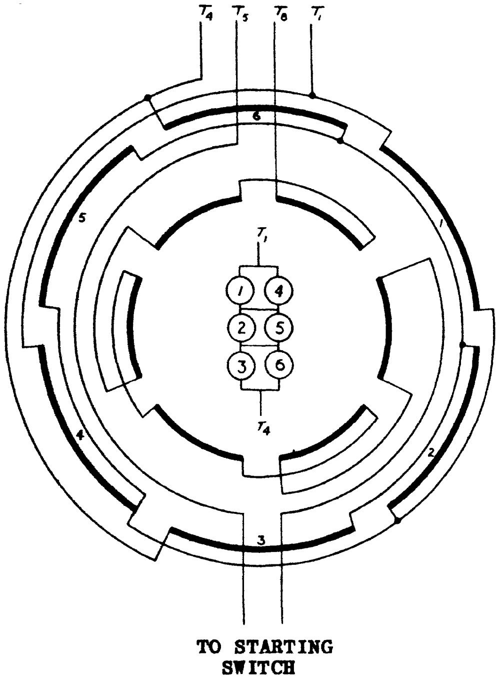


Fig. 11-17. Connection Diagram for 6 poles, main winding connected in 2 parallel paths, auxiliary winding connected in series.

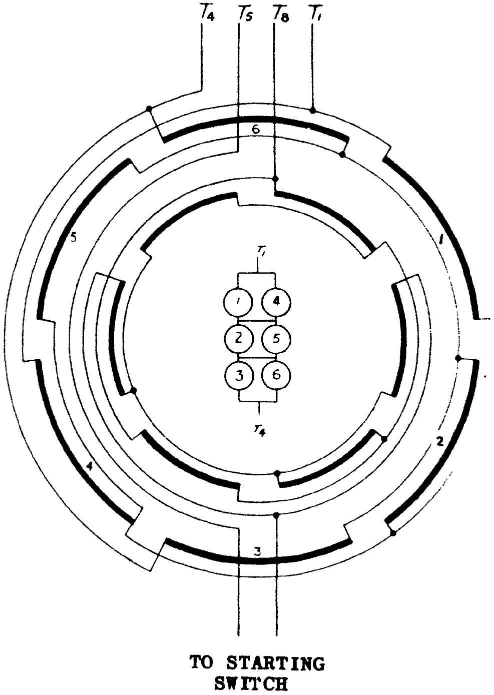


Fig. 11-18. Connection Diagram for 6 poles, both windings connected in 2 parallel paths.

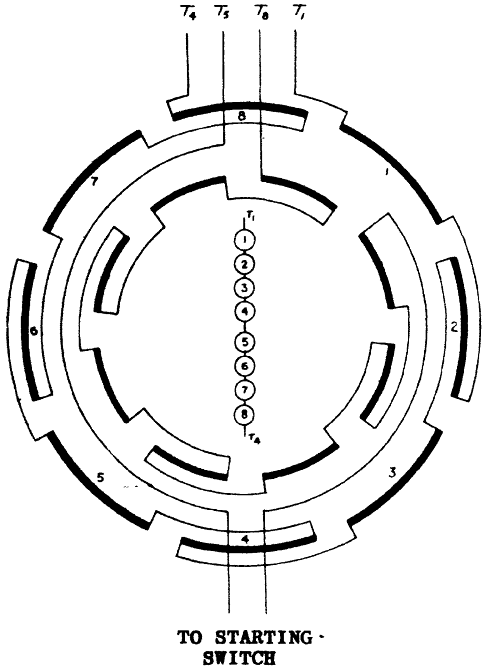


Fig. 11-19. Connection Diagram for 8 poles, both windings connected in series.

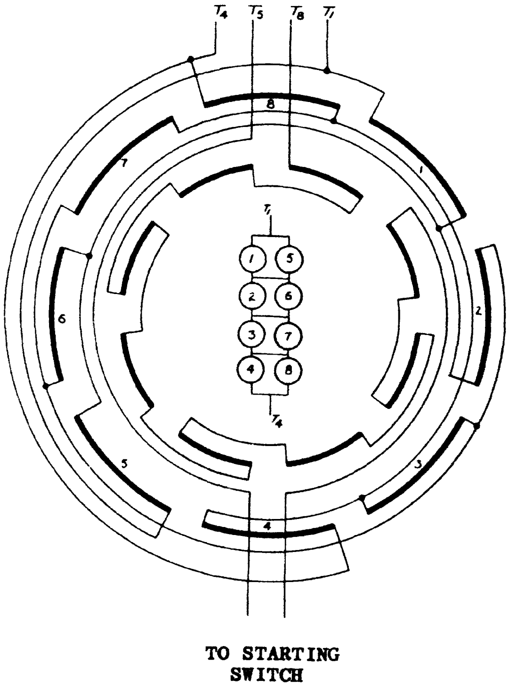


Fig. 11-20. Connection Diagram for 8 poles, main winding connected in 2 parallel paths, auxiliary winding connected in series.

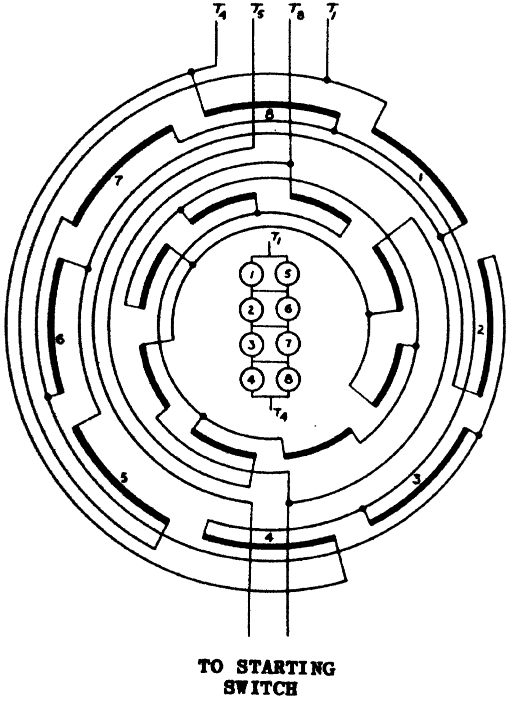


Fig. 11-21. Connection Diagram for 8 poles, both windings connected in 2 parallel paths.

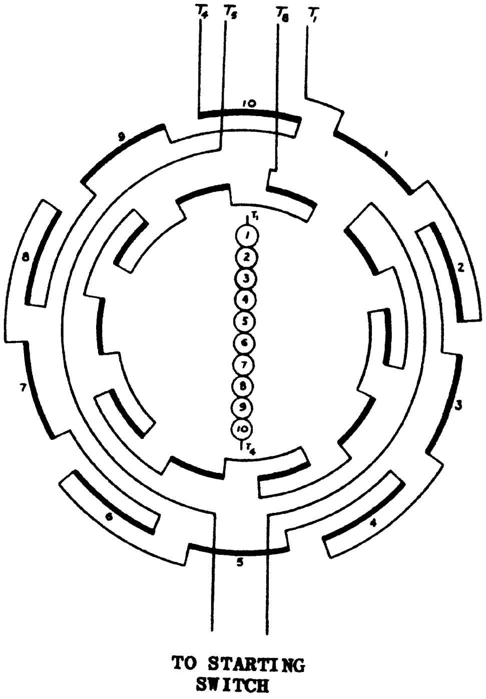


Fig. 11-22. Connection Diagram for 10 poles, both windings connected in series.

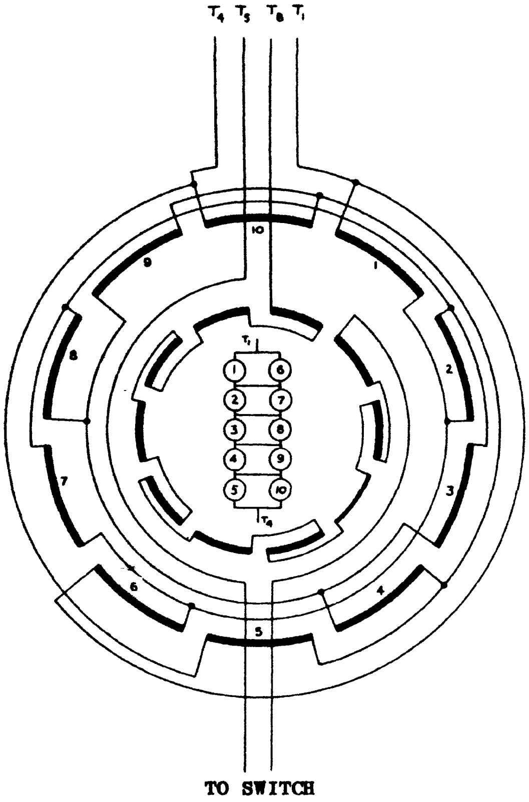


Fig. 11-23. Connection Diagram for 10 poles, main winding connected in 2 parallel paths, auxiliary winding connected in series.

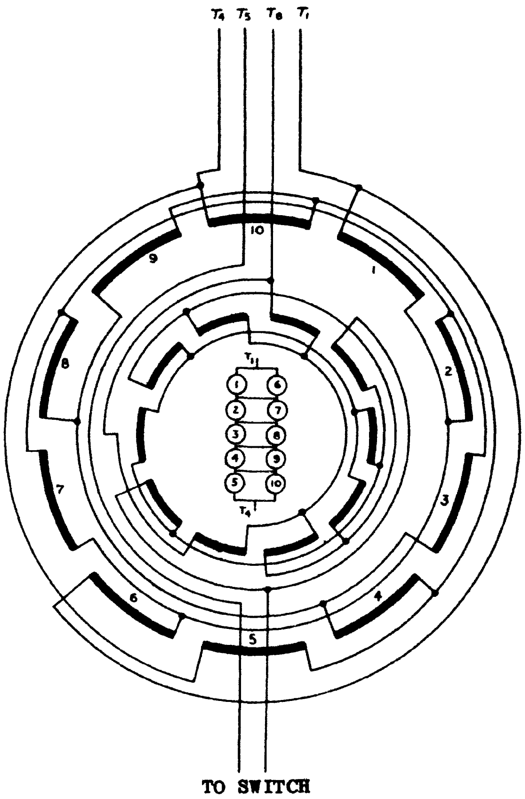


Fig. 11-24. Connection Diagram for 10 poles, both windings connected in 2 parallel paths.

CHAPTER 12

ELECTRICAL FAULTS IN A-C WINDINGS

The most common electrical faults in a-c windings are grounds, short circuits, wrong connections, and open circuits. In this chapter, these faults are described, and the means to locate them are given. At the end of the chapter a trouble chart is shown, listing numerous defects.

12-1. Grounds. A ground means contact between conductor-copper and iron. If the contact resistance is low, the fault may be detected by using a trouble light (Fig. 12-1), one lead of which is connected to the bare metal of the motor frame and the other lead to the copper (terminal or stub), or by using a "bell-ringing" magneto or battery set. If the contact resistance is high, a higher voltage (up to 2000 volts) is to be applied between frame iron and copper. The application of a higher voltage will heat up the contact, until smoke or arcing becomes

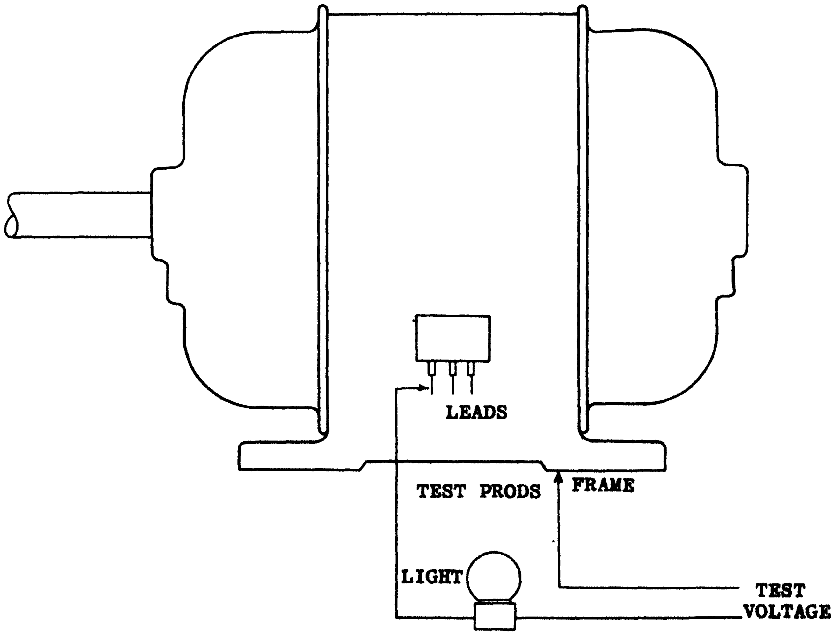


Fig. 12-1. Checking for a ground by use of a trouble light.

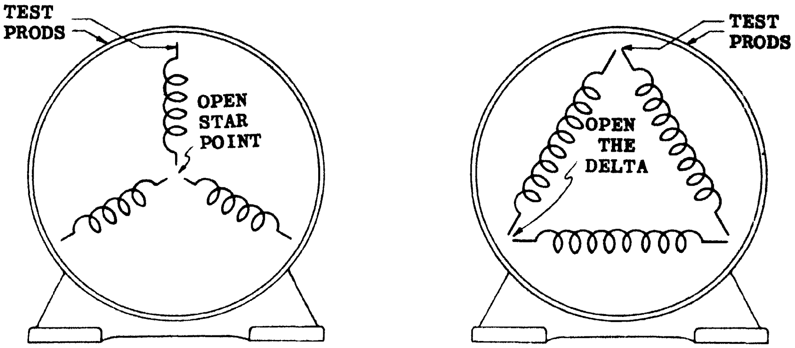


Fig. 12-2. If test shown in Fig. 12-1 shows the presence of a ground, the winding must be opened as shown and each phase tested to locate the grounded phase.

evident. Sometimes it will become necessary to open up the winding in several places and to investigate each winding part separately. This is illustrated in Figs. 12-2 and 12-3.

12-2. Short Circuits. One or more turns can be shorted in one or more coils and also a complete coil can be shorted at the coil ends. If the motor is running, the short-circuited turns or coil becomes overheated and often can be detected by feeling around the end-windings. This should not be done with machines of higher voltage. If the rotor is taken out, an internal growler can be used. Moving the growler around the stator core, the short-circuited turns or coil will be indicated by increased current in the growler primary. They may be detected also by attraction of a strip of sheet iron to the short-circuited turns

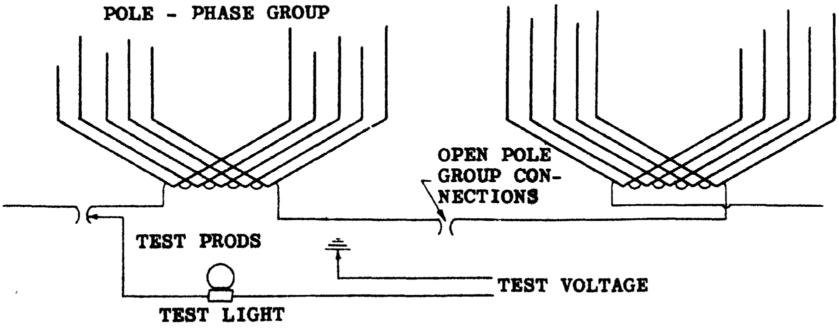


Fig. 12-3. Following the test of Fig. 12-2, the grounded phase is separated into its component parts and each part tested until the grounded part is located.

or coil, or by heating which takes place in the defective turns or coil. The internal growler can only be used when the winding is connected in series star. In order to use an internal growler in multiple circuit stators, it is necessary to open all parallel circuits.

Another method of locating the defect is to excite the winding with alternating current, preferably of higher frequency (200 to 400 cycles), and to touch a piece of steel or iron to the stator iron around the core. The location of the defect will be under the pole which shows a substantially weaker pull on the piece of steel or iron than the other poles.

A short-circuit of a complete pole-phase group can be located also by a "compass" test. For this purpose the winding is excited with a direct current approximately equal to 1/3 of the normal alternating current. The compass is moved around the stator core and the North and South poles marked (see Fig. 12-4). The marking will show whether the winding is correct or not. In 2-phase windings, each phase must be excited separately and the markings made. In 3-phase, star-connected windings, 3 observations and 3 markings are to be made. The d-c positive lead is applied in turn to the 3 leads of the winding while the d-c negative lead is connected to the neutral. The marking of each phase must start at the phase lead. If the result of the 3 markings is a sequence of North and South poles all around the

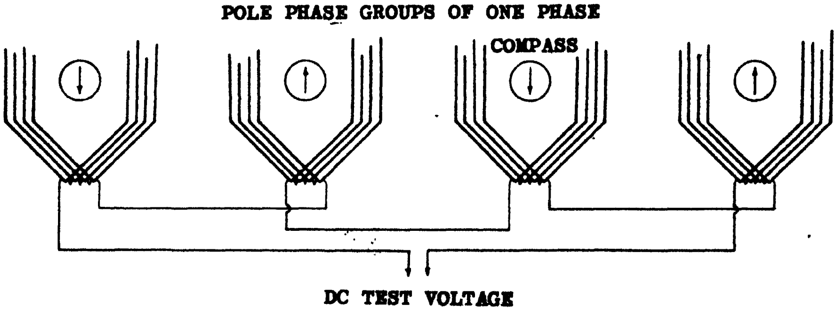


Fig. 12-4. A complete short-circuited pole-phase group is located by the compass test. Excite each phase by direct current approximately equal to 20% of the normal alternating current. The compass sequence (N or S) of each phase as shown above indicates that there are no short-circuited pole-phase groups. This test will also indicate reversed phase, or pole-phase group.

core, the winding has no short-circuited pole-phase groups. In 3-phase, delta-connected windings, the delta must be opened at one lead and connected to a d-c source. The direct current then flows through all 3 phases in series. For a correct winding, the North and South poles must alternate.

In order to locate the short circuit of a large part of a phase, the "balance test" can be made: each phase is separately excited by approximately 20% of the normal voltage and the current is measured. A higher current reading in one phase indicates a short-circuit in that phase (see Fig. 12-5). If the winding is delta-connected, the delta must be opened at one point and each phase measured separately.

12-3. Wrong Connections. A wrong connection exists when one or more single coils are reversed in the same pole-phase group, or when a pole-phase group is reversed, or when in a 3-phase winding a complete phase is reversed. In all 3 cases, the compass test described in the foregoing section can be applied. An incorrectly connected single coil will have the tendency to reverse the compass needle. In the case of a reversed pole-phase group, the compass needle will show the same field direction on 3 consecutive pole-phase groups. When a complete phase of a 3-phase winding is reversed, the compass test will show markings going in groups of 3 in opposite directions. A 3-phase motor with one phase reversed generally will not start and, if

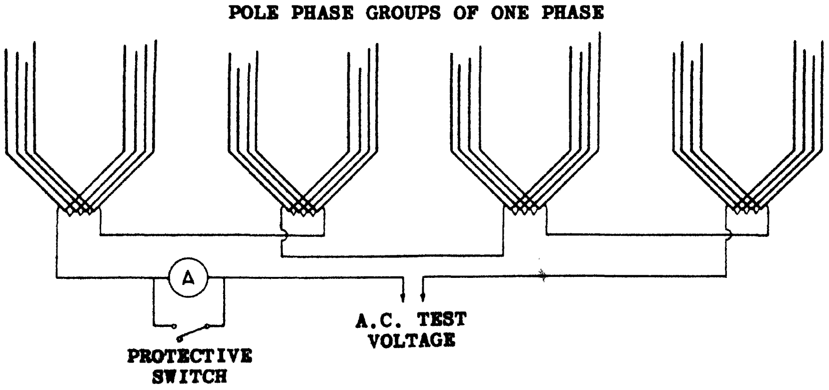


Fig. 12-5. Test each phase separately with approximately 20% of normal operating voltage. A higher current reading in one phase indicates a short circuit in that phase.

started, will produce a growling noise: the windings become hot after a short time of running.

In a lap winding, it is a simple matter to check the grouping in order to determine whether the sequence and number of single coils per group are correct. This can be done by inspection. In wave windings, such as are used in rotors, this cannot be done by inspection. However, by the use of a trouble-light or bell-ringing magneto or bettery set, the connections can be checked. This will be shown by an example. Whether the winding is connected star or delta, the phases must be disconnected from each other. However, the connecting jumpers within each phase must be left connected. Fig. 6-11 shows the complete winding diagram for a 72-slot rotor connected for 8 poles with the phases not connected together. The Working Diagram of this winding is shown by Fig. 6-27 and also in Fig. 12-6 with the addition of all the series clips and jumpers. If no error has been made in connecting the winding, then a test-light, with one end applied to A_1 and the other end free to contact every clip around the periphery of the rotor, will light in the sequence designated by solid dots in Fig. 12-6. It can be seen that the light appears symmetrically in groups of 3.

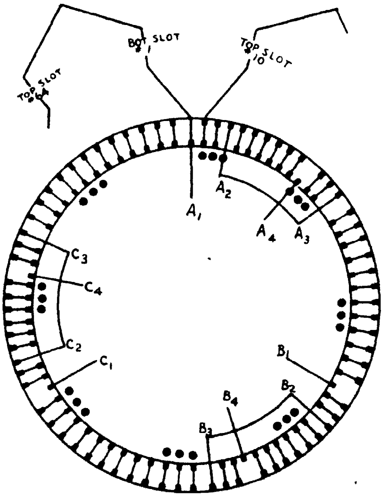


Fig. 12-6. Working Diagram showing the lighting sequence for a properly connected wave winding for 72 slots 8 poles and spp = 3. The dots represent lighting sequence for Phase A.

From the Master Table 3-5 for 72 slots and 8 poles spp is 3; this agrees with the grouping above. It can also be seen that between each group of 3 clips which light, there are 6 other clips or coils which do not light. These belong to phases B and C. They also will light in groups of 3 when the test-light is applied to phase B and C respectively. Any other lighting sequence will denote an incorrect connection. A lighting sequence is shown in Fig. 12-7 for an incorrect connection of the winding shown properly connected in Fig. 6-27. The error is a connection of upper coil side in slot 11 to bottom coil side in slot 2. This test can be applied to integral-slot as well as to fractional-slot wave windings. The lighting sequence will always agree with the groupings calculated by the methods outlined in Chapters 6, 7 and, 8.

12-4. Connection for Wrong Voltage. If a motor is incorrectly connected for a lower voltage than the line voltage, say for 110 volts while the line voltage is 220 volts, this will show up in an excessive no-load current and in a magnetic hum indicating that the flux is too high (see Eq. 10-1). If, on the other hand, the motor is incorrectly connected for a higher voltage

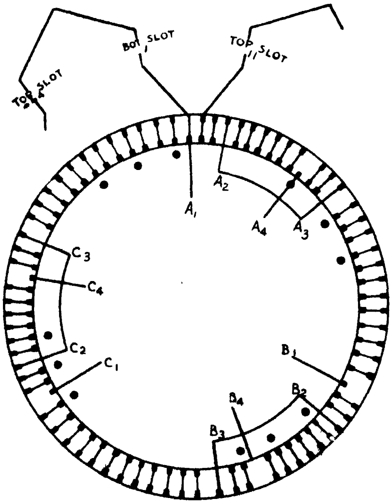


Fig. 12-7. Working Diagram showing lighting sequence of an incorrectly connected wave winding for 72 slots 8 poles and spp = 3. The error is a connection of upper coil side in slot 11 to bottom coil side in slot 2.

than the line voltage, the starting torque and pull-out torque will be reduced; for example, if a motor is connected for 220 volts while the line voltage is 110 volts, the starting torque and pull-out torque will be only 1/4 of the values at the right connection and the motor may not start and will pull out at a load smaller than the normal load.

If a 3-phase motor designed for star connection is connected delta, the line voltage will be 73% too high with all the consequences described above. Vice versa, if a 3-phase motor designed for delta connection is connected star, the line voltage will be 73% too low.

In a generator, a wrong connection shows up in the no-load voltage. A reconnection is to be made in the case of a wrong connection. The possibilities for this are treated in Art. 10-2.

12-5. Connection for a Wrong Number of Poles. A connection for a wrong number of poles will show up in the speed. The methods of reconnection for the right number of poles are treated in Art. 10-5.

12-6. Open Circuits. An open circuit may be due to a poorly soldered joint or a broken joint or conductor. A series star- or series delta-connected 3-phase motor with one phase interrupted will behave like a single-phase motor and will not start. If the winding is connected series star, the phase which is interrupted can be found by lighting-out or ringing-out the winding (see Art. 12-1) between the terminals (see Fig. 12-8). If the winding is connected series delta, the delta must be opened at one terminal and each phase tested separately again by a trouble-light or by a bell-ringing magneto or a battery set. After the faulty phase has been located, the investigation will have to be applied to parts of this phase. This is illustrated in Fig. 12-9.

If a 3-phase motor is connected parallel-star or parallel-delta and one or more but not all of the parallel circuits are interrupted in one of the phases, the motor may start. The defect will show up in vibration and over-heating of certain parts of the winding. The faulty phase can be best located by a balance test (see Art. 12-2). This phase must then be broken up

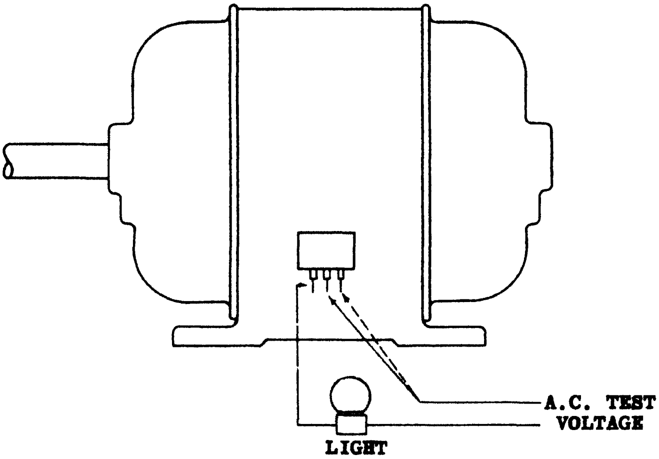


Fig. 12-8. If star-connected winding is open-circuited, the faulty phase is detected by lighting-out (or ringing out) the winding between terminals as shown. If delta, open the winding at one terminal and test each phase.

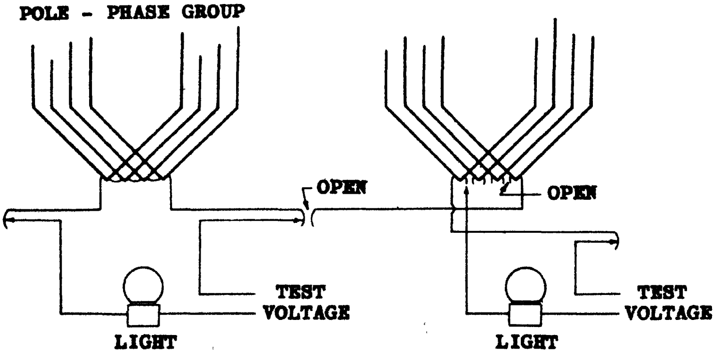


Fig. 12-9. The test of Fig. 12-8 indicates the open-circuited phase. Then, each component part of the open circuited phase is individually tested, leading eventually to the faulty coil or joint.

into its parallel circuits and each circuit investigated separately, as explained before.

An open circuit in a squirrel-cage rotor, i.e., defective brazing or defective die-casting of such a rotor, can be detected by slowly moving it in a single-phase field. For this purpose, a voltage of about 25% of the normal is to be impressed on 2 terminals of the stator. If the variation in the current is less than 3%, while the rotor is moved, it can be assumed that the rotor is satisfactory for use.

An open circuit in a squirrel cage can also be detected by means of a growler with an ammeter in the growler circuit. An open circuit or a high resistance joint will be indicated by a lower ammeter reading. Recently, squirrel-cage rotors are being investigated with respect to faults by X rays.

Open circuits in windings of wound rotors are to be treated in the same manner as those of stator windings.

TROUBLE SHOOTING CHART FOR INDUCTION MOTORS

Courtesy General Electric Company, Schenactady, N.Y.

TROUBLE	CAUSE	REMEDY
Motor will not start	Overload control trip.	Wait for overload to cool. Try starting again. If motor still does not start, check all the causes as outlined below.
	Power not connected.	Connect power to control, and control to motor. Check clip contacts.
	Faulty (open) fuses.	Test fuses.
	Low voltage.	Check motor-name plate values with power supply. Also check voltage at motor terminals with motor under load to be sure wire size is adequate.
	Wrong control connections.	Check connections with control wiring diagram.
	Loose-terminal-lead connection.	Tighten connections.
	Driven machine locked.	Disconnect motor from load. If motor starts satisfactorily, check driven machine.
	Open circuit in stator or rotor winding.	Compare winding resistance of various circuits using separate low voltage power source. Splice broken wires or rewind.
	Short circuit in stator winding.	Check winding resistance or use "Growler". Insert insulation at point of short or cut out shorted coil as temporary measure and rewind as soon as possible.
	Winding grounded.	Test for grounded winding.
	Bearings stiff.	Free bearings or replace.
	Grease too stiff.	Use special lubricant for special conditions.
	Faulty control.	Review instructions accompanying controller.
	Overload.	Reduce load.
Motor Noisy	Motor running single phase	Stop motor. Then try to start. It will not start on single phase. Check for "Open" in one of the lines or circuits.
	Electrical load unbalanced.	Check current balance by measuring current and voltage in each phase. Correct the power supply to obtain balanced voltages.
	Shaft bumping (Sleeve-bearing motors).	Check alignment and condition of belt. On pedestal-mounted bearing, check end play and axial centering of rotor.
	Vibration.	Driven machine may be unbalanced. Remove motor from load. If motor is still noisy, rebalance rotor.
	Air gap not uniform.	Center the rotor; if necessary replace bearings.
	Noisy ball bearings.	Check lubrication. Replace bearings if noice is persistent and excessive.
	Loose punchings, or loose rotor on shaft.	Tighten all holding bolts.
	Rotor rubbing on stator.	Center the rotor and replace bearings if necessary.
	Objects caught between fan and end shields.	Disassemble motor and clean it. Any rubbish around motor should be removed.
	Motor loose on foundation.	Tighten holding-down bolts. Motor may possibly have to be realigned.
	Coupling loose.	Insert feelers at four places in coupling joint before pulling up bolts to check alignment. Tighten coupling bolts securely.

TROUBLE SHOOTING CHART FOR INDUCTION MOTORS - Continued

TROUBLE	CAUSE	REMEDY
Motor operating at higher than normal temperature or smoking.	Overload.	Measure motor loading with ammeter and compare with full load current on name plate. Reduce load.
	Electrical load unbalance.	Check for voltage unbalance or single phasing.
	(Fuse blown. Faulty control, etc.)	Check for "Open" in one of the lines or circuits.
	Restricted ventilation.	Clean air passages and windings.
	Incorrect voltage and frequency.	Check motor-name plate values with power supply. Also check voltage at motor terminals with motor under full load.
	Motor stalled by driven machine or by tight bearings.	Remove power from motor. Check machine for cause of stalling.
	Stator winding shorted.	Locate shorted portion by resistance measurement or "Growler". Cut out coil for temporary use but rewind as soon as possible.
	Stator winding grounded.	Locate ground through resistance measurement and insert insulation at grounded point or rewind if necessary.
	Rotor winding with loose connections.	Tighten, if possible, or replace with another rotor.
	Belt too tight.	Remove excessive pressure on bearings.
	Motor used for rapid reversing service.	Replace with motor designed for this service.
Bearings Hot	End shields loose or not replaced properly.	Make sure end shields fit squarely and are properly tightened.
	Excessive belt tension or excessive gear side thrust.	Reduce belt tension or gear pressure and realign shafts. See that thrust is not being transferred to motor bearing.
	Bent shaft.	Straighten shaft, or send to service shop.
Sleeve Bearings	Insufficient oil.	Add oil; if oil supply is very low, drain, flush, and refill.
	Foreign material in oil or poor grade of oil.	Drain oil, flush, and relubricate using industrial lubricant recommended by a reliable oil company.
	Oil rings rotating slowly or not rotating at all.	Oil too heavy; drain and replace. Oil ring has worn spot; replace with new ring.
	Motor tilted too far.	Level motor or reduce tilt and realign, if necessary.
	Rings bent or otherwise damaged in reassembling.	Replace rings.
	Ring out of slot (oil ring retaining clip out of place).	Adjust or replace retaining clip.
	Motor tilted causing end thrust.	Relevel motor. Reduce thrust, or use motor designed for thrust.
	Defective bearings or rough shaft.	Replace bearings. Resurface shaft.

TROUBLE SHOOTING CHART FOR INDUCTION MOTORS - Concluded

TROUBLE	CAUSE	REMEDY
Bearings Hot Ball Bearings	Too much grease.	Remove relief plugs, and let motor run. If excess grease does not come out, flush and relubricate. Housing should be about one half full. Use relief plug to relieve pressure.
	Wrong grade of grease.	Add proper grease.
	Insufficient grease.	Remove relief plug and regrease bearing.
	Foreign material in grease.	Flush bearings. Relubricate; make sure that grease supply is clean. (Keep can covered when not in use).
	Bearings misaligned.	Align motor and check bearing-housing assembly. See that races are exactly 90 degrees with shaft.
	Bearings damaged (Corrosion, etc.).	Replace bearings.
Wound-Rotor Motor Troubles Motor runs at low speed with external resistance cut out.	Wires to control too small.	Use larger cable to control.
	Control too far from motor.	Bring control nearer motor.
	Open in rotor circuit (including cable to control).	Test by ringing out circuit and repair.
	Brushes sparking.	Check for overload with ammeter and eliminate overload. Clean rings and refit brushes.
	Dirt between brush and ring.	Clean rings and insulation assembly.
	Brushes stuck in holders.	Use right size brush.
	Incorrect brush tension.	Check brush tension and correct.
	Rough collector rings.	File, sand and polish.
	Eccentric rings.	Turn in lathe or use portable tool to true up rings, without disassembling motor.
	Excessive vibration.	Balance motor.
	Current density of brushes too high (overload).	Reduce load. (If brushes have been replaced, make sure they are of the same grade as originally furnished).

APPENDIX 1

BALANCED FRACTIONAL-SLOT LAP WINDINGS LAID OUT WITH RESPECT TO THE MAIN WAVE

A1-1. Number of Repeatable Groups and Parallel Paths. The number of slots per pole per phase (spp) will be designated by q. In fractional-slot windings, q can be represented as

$$q = \frac{N}{d} = I + \frac{n}{d} \qquad \text{(A1-1)}$$

where neither N and d nor n and d have a common divisor and I is an integer. It will be shown in Art. A1-5 that, for balance, d must not be divisible by the number of phases. The latter will be designated by m. The total number of slots will be designated by S and the number of poles by p.

With the notations of Eq. A1-1, the winding repeats itself after each d poles, and the number of recurrent winding parts is equal to $\frac{p}{d}$. Each phase has N slots in d poles.

This can be understood best by an example. Consider the stator winding of a 3-phase machine having 20 poles and S = 135 slots. Then

$$q = \frac{135}{3 \times 20} = \frac{9}{4} = 2 + \frac{1}{4}$$

i.e., d = 4, N = 9, I = 2, n = 1. Since each pole-phase group must have an integral number of single coils (2 or 3 or 4, etc.), $q = 2\frac{1}{4}$ can be realized if each phase has in 4 poles 3 pole-phase groups with 2 single coils and 1 pole-phase group with 3 single coils, making $\frac{3 \times 2 + 1 \times 3}{4} = \frac{9}{4}$ slots per pole per phase. Thus, 4 poles constitute a repeatable winding part, and each phase has in 4 poles $N = 4 \times \frac{9}{4} = 9$ slots. There is a maximum of $\frac{20}{4} = 5$ (in general $\frac{p}{d}$) parallel circuits possible, while a 20-pole machine with q = integer may have 20 parallel circuits.

Hence, if $q = \frac{N}{d} = I + \frac{n}{d}$, there are $\frac{p}{d}$ recurrent winding parts in each phase and each phase has N slots in d poles. Further, each phase has in d poles (d - n) pole-phase groups with I single coils, and n pole-phase groups with (I + 1) single coils.

A1-2. The Slot Star. The fractional-slot windings can be studied best on the basis of the slot star which shows the position of the individual slots in the magnetic field. Since there are 2 coil sides in each slot, the slot star also shows the position in the magnetic field of the upper and lower coil sides, i.e., of upper and lower layer. It suffices to consider only one of the 2 layers.

Fig.A1-1 shows the slot star of a 2-pole, 3-phase, integral-slot winding with q = 2. The angle between 2 adjacent slots is, in general

$$\alpha_s = \frac{180}{m\ q} \qquad \text{(A1-2)}$$

and in this case $\alpha_s = \frac{180}{3 \times 2}$ = 30 electrical degrees. Two adjacent vectors represent 2 adjacent slots or 2 adjacent coil sides of the same layer. Considering the upper layer, coil sides 1 and 2 belong to phase A, coil sides 3 and 4 belong to phase C, and coil sides 5 and 6, to phase B. Vector 7 which represents coil side 7 starts the second pole and is shifted 180° with respect to vector 1; vector 8 is shifted 180° with respect to vector 2, and so on, i.e., the bottom half of the slot star is the same as the top half, except that their vectors are shifted by 180°.

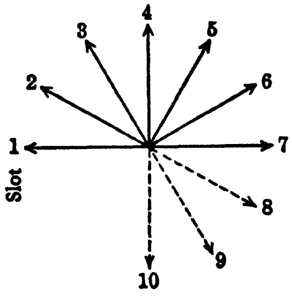


Fig. A1-1. Slot star of an integral-slot 3-phase winding with 2 slots per pole per phase.

Fig. A1-2 shows the 4 coils belonging to phase A. The connector C takes care that the emf or mmf of coil side 1 adds to that of coil side 7 and that the emf or mmf of coil side 2 adds to that of coil side 8. In the slot star which shows the phase displacements between the single coil sides of the winding, vector 7 can be made to coincide with vector 1, vector 8 with vectow 2, and so forth, i.e., the slot star of the 2-pole integral-slot winding is completely represented by the vectors of 1 pole which require only half of a circle. Since two poles are the unit (recurrent part) of the integral-slot winding, this result applies to the integral-slot windings in general.

d poles make the unit (recurrent part) of the fractional-slot winding, just as 2 poles make the unit of the integral-slot

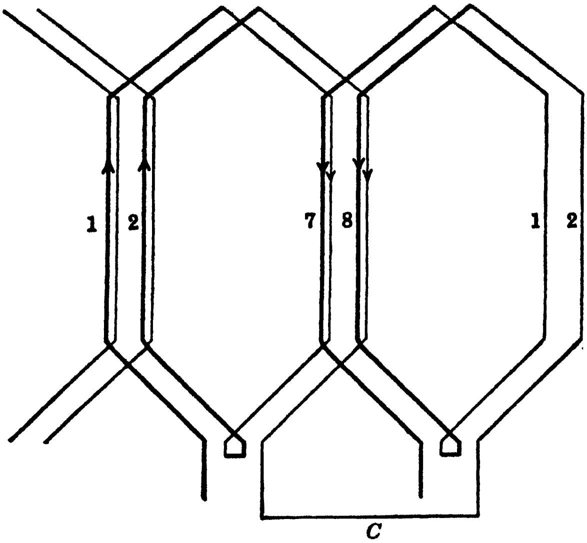


Fig. A1-2. Connection between 2 consecutive pole-phase groups.

winding; therefore, the slot star of d poles of the fractional-slot winding is represented by half of a circle.

Fig. A1-3 shows the slot-star of a 3-phase, fractional-slot winding with $1\frac{1}{4}$ slots per pole per phase, i.e., $d = 4$, $N = 5$, $I = 1$, $n = 1$. $d = 4$ poles make a unit (recurrent part). Each phase has $N = 5$ slots in $d = 4$ poles. There are in $d = 4$ poles, per phase, $d - n = 4 - 1 = 3$ pole-phase groups with $I = 1$ single

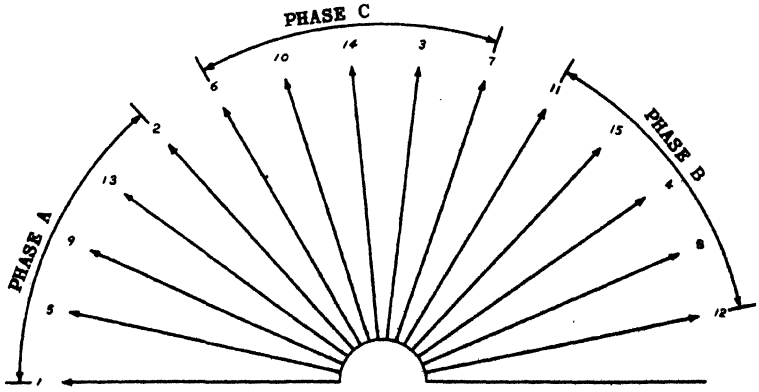


Fig. A1-3. Slot star of a fractional-slot 3-phase winding with $q = 1\ 1/4$.

coil and n = 1 pole-phase group with I + 1 = 1 + 1 = 2 single coils. The total number of slots in d = 4 poles is mN = 3 x 5 = 15. The slot star, therefore, contains 15 vectors.

The angle between 2 adjacent slots is (Eq. A1-2):

$$\alpha_s = \frac{180}{3 \times 1\frac{1}{4}} = 48^\circ$$

i.e., the angle between vectors 1 and 2, 2 and 3, etc., is 48°. The angles which correspond to the 15 slots of the unit (d = 4 poles) are:

Slot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Angle	0	48	96	144	192	240	288	336	24	72	120	168	216	264	312

To slot 16, there corresponds the angle 360° or 0°; slot 16 is the beginning of the next recurrent part. Slots 1 to 4 lie under the first pole of the unit; slots 5 to 8 lie under the second pole; slots 9 to 12 under the third pole; and slots 13 to 15 under the fourth pole. Since the connections between the coil groups take into account the shift of 180° (Fig. A1-2), the real angles between the slots, i.e., the shifts of the slots with respect to each other in the magnetic field, are:

Slot	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Angle	0	48	96	144	12	60	108	156	24	72	120	168	36	84	132

and these angles appear in the slot star (Fig. A1-3). Note that between the vectors 1 and 2, which correspond to slots 1 and 2, lie the 3 vectors which correspond to the slots 5, 9, and 13; that between the vectors 2 and 3, which correspond to slots 2 and 3, lie the 3 vectors which correspond to the slots, 6, 10, and 14, and so on, i.e., the winding creeps in the magnetic field. It is necessary to distinguish between the angle between 2 slots as given by Eq. A1-2 and the angle between 2 adjacent vectors α_m. This latter angle is the magnetic-field angle between the slots (coil sides) of the recurrent winding part; this angle determines the behavior of the winding with respect to its mmf and emf, i.e., this angle determines the distribution factors of the winding with respect to the main wave and harmonics.

The magnetic-field angle is:

$$\alpha_m = \frac{180}{Nm} \tag{A1-3}$$

α_m is equal to α_s only for the integral-slot winding. For the fractional-slot windings, α_m is always smaller than α_s. The ratio $\frac{\alpha_s}{\alpha_m}$ (see Eqs. A1-2 and A1-3) is equal to $\frac{N}{q}$, i.e., between 2 adjacent slots of the slot star, for example, between slot 1 and 2, there are ($\frac{N}{q} - 1 = d - 1$) other slots (vectors). In Fig. A1-3, there are between 2 adjacent slots $(4-1) = 3$ other vectors. Note that the slot star considered above refers to the main wave, since in Eqs. A1-2 and A1-3 an angle of 180^o has been used for the pole pitch.

Apparently the largest distribution factor for the main wave will be obtained when the first 5 vectors of the slot-star, Fig. A1-3, are assigned to phase A, the following 5 vectors are assigned to phase C, and the last 5 vectors to phase B, because the closer the slots which belong to each phase lie together in the slot star, the larger the distribution factor. Thus, in each recurrent part, phase A will occupy the slots 1, 5, 9, 13, and 2: phase C, the slots 6, 10, 14, 3, and 7: and phase B, the slots 11, 15, 4, 8, and 12.

Consider the sequence of the slots in the slot star, Fig. A1-3. Starting with slot 1, the sequence of the slots follow the series

$$1, \quad 1 + 4, \quad 1 + 2 \times 4, \quad 1 + 3 \times 4, \quad 1 + 4 \times 4 - 15 = 2 \ldots.$$

Since the total number of slots in the recurrent part is equal to mN, this value (or multiple of it) is to be subtracted from the terms of this series if they become larger than mN.

In general, the series is:

$$1, \quad 1 + D, \quad 1 + 2D, \quad 1 + 3D \ \ldots \ 1 + (3N-1)D \qquad \text{(A1-4)}$$

where D is the difference between 2 slots which correspond to 2 adjacent vectors of the slot star. In the example considered above, $D = 4$.

This difference D can be found from the following consideration. If P denotes the number of full pole pitches between 2 slots which correspond to 2 adjacent vectors of the slot star (in Fig. A1-3, $P = 1$), then there will be

$$D \times \alpha_s = \alpha_m + 180 \ P$$

Inserting α_s and α_m from Eqs. A1-2 and A1-3, there results

$$D = \frac{mNP + 1}{d} \qquad \text{(A1-5)}$$

The smallest integer which makes D an integer must be used for P in this equation. P is equal to or larger than 1.

Having the value of D, it is very simple to lay out the winding.

A1-3. The Layout of a Balanced Fractional-slot Lap Winding. The layout of a fractional-slot lap winding on the basis of the slot star will be demonstrated by an example.

Assume $p = 10$, $m = 3$, $q = 1\frac{3}{5} = \frac{8}{5} = 1 + \frac{3}{5}$, i.e., $d = 5$, $N = 8$. 5 poles make a unit (recurrent part). There will be, in 5 poles, $3 \times N = 24$ slots, $N = 8$ for each phase. Each phase will have, per unit, $n = 3$ pole-phase groups with 2 single coils, and $d - n = 5 - 3 = 2$ pole-phase groups with one single coil. It follows from Eq. A1-5 that

$$D = \frac{3 \times 8 \times P + 1}{5} = 5 \text{ with } P = 1$$

The N = 8 slots which belong to phase A, therefore, follow the series

1 1+D 1+2D 1+3D 1+4D 1+5D-3N 1+6D-3N 1+7D-3N
1 6 11 16 21 2 7 12

or, arranged corresponding to the sequence of the slots in the machine,

1-2 6-7 11-12 16 21

The 8 slots which belong to phase C are

1+8D-3N 1+9D-3N 1+10D-6N 1+11D-6N 1+12D-6N
17 22 3 8 13

1+13D-6N 1+14D-6N 1+15D-9N
18 23 4

or, arranged corresponding to the sequence of the slots in the machine,

3-4 8 13 17-18 22-23

The 8 slots which belong to phase B are

5 9-10 14-15 19-20 24

Figure A1-4 shows the slot star of this winding.

Starting with slot 1 and considering the slots assigned to the 3 phases, the first pole-phase group consists of slots 1 and 2 and belongs to phase A. The second pole-phase group consists of slots 3 and 4 and belongs to phase C. The third pole-phase group consists of slot 5 and belongs to phase B, and so forth.

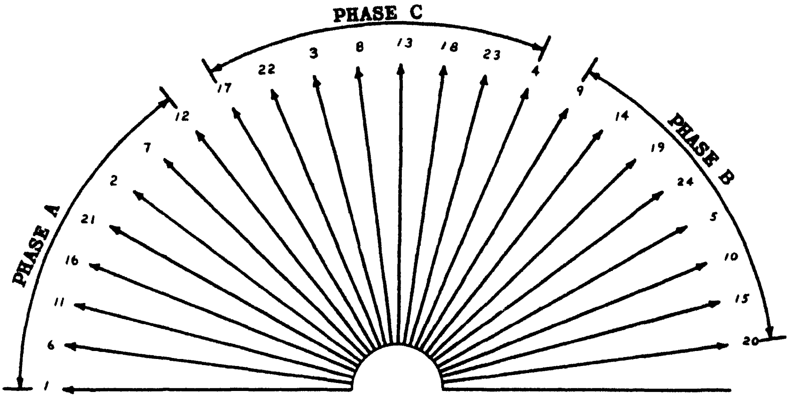


Fig. A1-4. Slot star of a fractional-slot 3-phase winding with q = 1 3/5.

The sequence of the pole-phase groups in a recurrent part of the winding is

2	2	1	2	1	2	2	1	2	1	2	2	1	2	1
A	C	B	A	C	B	A	C	B	A	C	B	A	C	B

In the example considered, p = 10. Thus, the number of recurrent parts is $\frac{p}{d} = \frac{10}{5} = 2$, and the sequence of the pole-phase groups around the stator is twice the sequence found for one recurrent part.

Note that the grouping found for one recurrent part consists of 3 repetitions of the grouping.

2 2 1 2 1

Therefore, it suffices to know the grouping of only a third of one recurrent part and to repeat this grouping 6 times. (An explanation of this fact is given below.)

The number of pole phase groups in one recurrent part, i.e., in d poles, is m x d = 3 x 5 = 15, and a third of this number is d = 5. Hence, in general, it is necessary to determine the sequence of only d pole-phase groups, in order to know the sequence of all pole-phase groups around the winding. For a 3-phase winding, the grouping of the d pole-phase groups repeats $3 \times (\frac{p}{d})$ times and, in 2-phase windings, $2 \times (\frac{p}{d})$ times.

The determination of the d pole-phase groups can be made on the basis of the D-Series (Eq. A1-4), as just shown in the example. There is also a shorter way to find these pole-phase groups.

Considering again at first the 3-phase windings, the first 60° of the slot star are assigned to phase A, the next 60° to phase C, the next 60° to phase B, and so on. Then the first pole-phase group of phase A will consist of the first $\left(\left|\frac{60}{\alpha_s}\right| + 1\right)$ consecutive slots, since $\left|\frac{60}{\alpha_s}\right|$ angles of α_s are contained in the 60° angle assigned to phase A. (The 2 vertical lines indicate that the integral part of the quantity is to be taken.) One is to be added to $\left|\frac{60}{\alpha_s}\right|$ because the first slot of the star is denoted by 1 and assigned to phase A. The first pole-phase group of phase C consists of the

$$\left(\left|\frac{120}{\alpha_s}\right| + 1\right) - \left(\left|\frac{60}{\alpha_s}\right| + 1\right)$$

next following consecutive slots. The first pole-phase group of phase B consists of the

$$\left(\left|\frac{180}{\alpha_s}\right| + 1\right) - \left(\left|\frac{120}{\alpha_s}\right| + 1\right)$$

following consecutive slots. The second pole-phase group of phase A consists of the

$$\left(\left|\frac{240}{\alpha_s}\right| + 1\right) - \left(\left|\frac{180}{\alpha_s}\right| + 1\right)$$

consecutive slots and so on. Since $\alpha_s = \frac{180}{mq}$ (Eq. A1-2):

$$\frac{60}{\alpha_s} = \frac{60}{180}\, mq = q$$

$$2 \times \frac{60}{\alpha_s} = \quad = 2q$$

$$3 \times \frac{60}{\alpha_s} = \quad = 3q$$

and so forth. Thus, the first pole-phase group of phase A consists of the first $(|q| + 1)$ single coils. The first pole-phase group of phase C of the following $(|2q| + 1) - (|q| + 1)$ single coils; the first pole-phase group of phase B of the next following $(|3q| + 1) - (|2q| + 1)$ single coils, and so on.

Consider the same winding as before, namely, $q = 1\frac{3}{5}$. In order to determine the number of single coils in the first 3 pole-phase groups, write

$$\begin{array}{ll}
\text{(a)} & \qquad\qquad\quad q \qquad\qquad\quad 2q \qquad\qquad\quad 3q \\
\text{(b)} & \underbrace{0 \qquad\quad |q|}_{\text{difference}}\underbrace{+1 \qquad |2q|}_{\text{difference}}\underbrace{+1 \qquad |3q|}_{\text{difference}}+1
\end{array}$$

i.e.,

$$\begin{array}{ll}
\text{(a)} & \qquad\qquad\quad 1\frac{3}{5} \qquad\qquad\quad 3\frac{1}{5} \qquad\qquad\quad 4\frac{4}{5} \\
\text{(b)} & \underbrace{0 \qquad\quad 1+1}_{2}\underbrace{=2 \qquad 3+1}_{2}\underbrace{=4 \qquad 4+1}_{1}=5 \\
 & \qquad\quad A \qquad\qquad\quad C \qquad\qquad\quad B
\end{array}$$

This is in accordance with the result found from the D-series.

Consider now the dth pole-phase group. Since $q = \frac{N}{d}$, for this coil group,

$$\frac{d \times 60}{\alpha_s} = \frac{d \times 60}{180} \times mq = N$$

i.e., the total angle d x 60, which corresponds to the dth pole-phase group, comprises an integral number of angles α_s and, therefore, ends in a slot. Since the total angle d x 60 is a multiple of 60^o, the slot in which the angle d x 60 ends is the beginning of the following phase (see slot star Fig. A1-3 or A1-4) and, therefore, this slot is to be subtracted from the number of slots contained in d x 60^o. Thus, the number of single coils (slots) of the dth pole-phase group is

$$(N-1+1) - \left\{\left|\frac{(d-1)x60}{\alpha_s}\right| + 1\right\} = N - \left\{\left|\frac{(d-1)x60}{\alpha_s}\right| + 1\right\}$$

Consider now the (d+1)th pole-phase group. To this coil group corresponds the total angle (d+1) x 60^o and the number of single coils of this pole-phase group is

$$\left\{\left|\frac{(d+1)x60}{\alpha_s}\right| + 1\right\} - N = N + \left|\frac{60}{\alpha_s}\right| + 1 - N = \left|\frac{60}{\alpha_s}\right| + 1$$

The number of single coils of the (d+2)th pole-phase group is

$$\left\{\left|\frac{(d+2)x60}{\alpha_s}\right| + 1\right\} - \left\{\left|\frac{(d+1)x60}{\alpha_s}\right| + 1\right\} = \left\{N + \left|\frac{2 \text{ x } 60}{\alpha_s}\right| + 1\right\} -$$

$$\left\{N + \left|\frac{60}{\alpha_s}\right| + 1\right\} = \left\{\left|\frac{2 \text{ x } 60}{\alpha_s}\right| + 1\right\} - \left\{\left|\frac{60}{\alpha_s}\right| + 1\right\}$$

i.e., the (d+1)th pole-phase group has the same number of single coils as the first pole-phase group, the (d+2)th pole-phase group has the same number of single coils as the second pole-phase group, and so on. It follows from this that the coil grouping starts repeating after the dth pole-phase group. This explains why the grouping for only d pole-phase groups is to be determined. Thus, it is sufficient to write

$$\begin{array}{lccccccccc}
\text{(a)} & & & q & & 2q & & 3q\ldots\ldots\ldots dq(=N) & & \\
\text{(b)} & 0 & & |q|+1 & & |2q|+1 & & |3q|+1\ldots\ldots dq & & \\
\text{(c)} & & \text{difference} & & \text{difference} & & \text{difference} & & \text{difference} &
\end{array} \qquad \text{(A1-6)}$$

The differences represent the coil grouping for N slots. Since the slot star contains mN slots, the grouping obtained is to be repeated m times in order to get the grouping of one repeatable part. Since there are $\frac{p}{d}$ repeatable parts, the grouping obtained for d pole-phase groups must be repeated $(m\times\frac{p}{d})$ times in order to obtain the coil grouping for the whole winding.

Applying this to the example with $m = 3$, $q = 1\frac{3}{5}$, $N = 8$, $d = 5$,

$$\begin{array}{lccccccccccc}
\text{(a)} & & & 1\frac{3}{5} & & 3\frac{1}{5} & & 4\frac{4}{5} & & 6\frac{2}{5} & & 8 \\
\text{(b)} & 0 & & 2 & & 4 & & 5 & & 7 & & 8 \\
\text{(c)} & & 2 & & 2 & & 1 & & 2 & & 1 &
\end{array}$$

This is the same grouping as obtained before from the D-series. For p = 10, repeat this grouping $(3 \times \frac{10}{5}) = 6$ times.

The considerations applied to the 3-phase windings apply also to the 2-phase windings. The first pole-phase group of the 2-phase winding consists of the first $\left|\frac{90}{\alpha_s}\right| + 1$ consecutive slots.

The second pole-phase group consists of the next following $\left[\left(\left|\frac{180}{\alpha_s}\right| + 1\right) - \left(\left|\frac{90}{\alpha_s}\right| + 1\right)\right]$ consecutive slots, and so on.

Since $\alpha_s = \frac{180}{mq}$,

$$\frac{90}{\alpha_s} = \frac{90}{180} \times mq = q$$

$$2 \times \frac{90}{\alpha_s} = \qquad = 2q$$

$$3 \times \frac{90}{\alpha_s} = \qquad = 3q$$

and so on. This is the same as for the 3-phase windings. Furthermore,

$$\frac{d \times 90}{\alpha_s} = \frac{d \times 90}{180} \times mq = N$$

Therefore, the same scheme is to be applied as for $m = 3$ in order to determine the number of single coils in the d pole-phase groups.

A further simplification in the layout of balanced fractional-slot lap windings with maximum distribution factor of the main wave is based on the following considerations:

Consider a 3-phase winding with $q = 2\frac{3}{5}$, $N = 13$, $d = 5$. The grouping of this winding is

$$\begin{array}{lcccccc} (a) & & 2\frac{3}{5} & 5\frac{1}{5} & 7\frac{4}{5} & 10\frac{2}{5} & 13 \\ (b) & 0 & 3 & 6 & 8 & 11 & 13 \\ (c) & & 3 & 3 & 2 & 3 & 2 \end{array}$$

Comparing this grouping with that determined for $q = 1\frac{3}{5}$, i.e.,

$$2 \quad 2 \quad 1 \quad 2 \quad 1$$

it is found that the sequence of the larger and smaller pole-phase groups is the same.

In general, if the number of slots per pole per phase is written as $q = I + \frac{n}{d}$, the sequence of the larger and smaller groups does not depend on the value of the integral part of q, i.e., I, but it depends only upon the values of n and d. If the distribution has been determined for a certain value of I, say for $I = 1$, the distribution for $I = 3$ is found by adding $2 = (3-1)$ to all numbers of the distribution for $I = 1$. Thus, the sequence of the larger and smaller pole-phase groups can be determined for $I = 0$, and then the same sequence applies to $I = 1, 2, 3, 4 \ldots.$ The value of I determines then the number of single coils in the pole-phase groups. The distribution found for $I = 0$ yields coil groups with 1 and 0 single coils. Adding 1 to all figures of the distribution for $I = 0$, the distribution for $I = 1$, is found; adding 2 to all figures of the distribution for $I = 0$, the distribution for $I = 2$, is found, and so on.

In order to determine the distribution for $I = 0$,

(a) Write the series $\frac{n}{d}$, $2\frac{n}{d}$, $3\frac{n}{d}$ ... $d\frac{n}{d}$.

(b) Add 1 to all integers of the (a) series except to the last number, $d\frac{n}{d} = n$.

(c) Write 0 to the left of the (b) series and determine the difference between adjacent numbers.

(d) Add to all numbers of the (c) series the value of I.

The last series represents the coil grouping of the $\frac{1}{m}$th part of a repeatable part. Repeat $(m \times \frac{p}{d})$ times in order to get the pole-phase group distribution for the whole winding.

From the coil distribution for $\frac{n}{d}$, the coil distribution for $\frac{d - n}{d}$ can be easily found by writing the $\frac{n}{d}$ distribution backwards and changing the ones to zeros and the zeros to ones Consider, for example, $\frac{n}{d} = \frac{2}{7}$. For these values of n and d the distribution is

1 0 0 1 0 0 0

For $\frac{d - n}{d} = \frac{7 - 2}{7} = \frac{5}{7}$, the distribution is

1 1 1 0 1 1 0

The simplified method of laying out balanced fractional-slot lap windings with maximum distribution factor of the main wave described in the foregoing has been used to derive Tables 4-1 and 4-2 for m = 2 and m = 3, respectively.

A1-4. Beginnings of Phases. Consider Fig. A1-4 which represents the slot star of a 3-phase winding with $q = 1\frac{3}{5}$. The first N = 8 slots (vectors) of the slot star are assigned to phase A, the following 8 slots (vectors) to phase C, and the last 8 slots (vectors) to phase B. Since the sequence of geometric addition of several vectors is of no influence on the resultant vector, any of the 8 slots of a phase can be taken as the beginning of the phase. However, care must be taken that no phase is reversed, i.e., the beginnings of the phases must lie approximately 120° and 240° apart and not approximately 60° and 120° apart. Thus the beginnings of the phases can be placed in the slots 1, 5, and 8, each of which belongs to a different phase.

The angle between 2 slots is (Eq. A1-2):

$$\alpha_s = \frac{180 \times 5}{3 \times 8} = 37.5^\circ$$

and the angles between the beginnings of the 3 phases are then $(5-1) \times 37.5 = 150^\circ$ and $(8-1) \times 37.5 = 262.5^\circ$. In a 3-phase winding with $q = 1\frac{1}{4}$, the beginnings of the phases can be placed in the slots 1, 4, and 6, which are 144° and 240° apart (see also Art. 4-11). These windings are balanced, i.e., their 3 emf's are equal and the angles between them are 120° and 240°, despite the fact that the angles between the beginnings of the phases are not equal to 120° and 240°.

In 2-phase windings, the beginnings of the phases must lie approximately 90° apart, i.e., the beginnings of any 2 consecutive pole-phase groups can be chosen as phase beginnings (see also Art. 4-9).

A1-5. Conditions for Balance. It has been mentioned in Art. A1-1 that, when d is divisible by the number of phases m, the winding is unbalanced, i.e., the emf's and mmf's of the different phases have unequal magnitudes and the angles between them are not equal to 90° when $m = 2$, or 120° and 240° when $m = 3$.

Consider a 3-phase winding with $q = 2\frac{2}{3}$, i.e., $N = 8$ and $d = 3$ d is divisible by the number of phases 3. Applying Eq. A1-5,

$$D = \frac{3 \times 8 \times P + 1}{3} = 8\,P + \frac{1}{3}$$

Since P is an integer, D cannot become an integer, i.e., Eq. A1-5 fails in this case. It will be shown in Appendix 3 that the kind of slot star, shown in Figs. A1-3 and A1-4, is not applicable in this case. When d is divisible by m, the winding is unbalanced.

A further condition for balance is that the total number of slots, S, is divisible by m, i.e.,

$$\frac{S}{m} = \frac{pqm}{m} = pq = \frac{p}{d}\,N = \text{integer}$$

Since N and d have no common divisor (see Eq. A1-1), the second condition for balance means that the number of poles must be divisible by d.

Thus, the conditions for balance are

$$\frac{p}{d} = \text{integer}$$

$$\frac{d}{m} \neq \text{integer} \qquad \text{(A1-7)}$$

(not integer) but fractional

The number of repeatable parts in each phase, and therefore the maximum possible number of parallel circuits, are equal to $\frac{p}{d}$.

APPENDIX 2

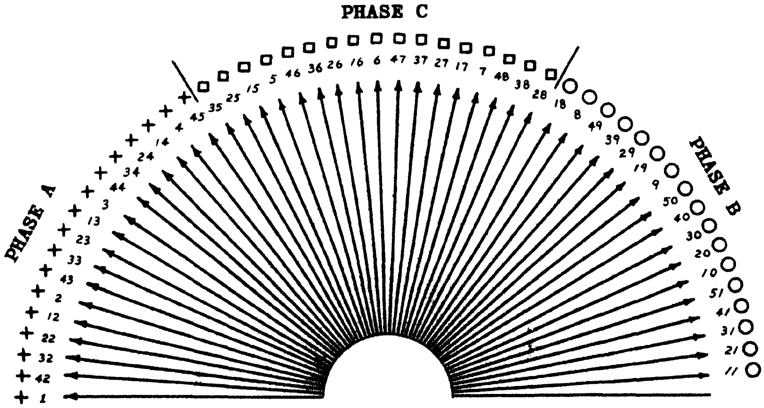
BALANCED FRACTIONAL-SLOT LAP WINDINGS LAID OUT WITH RESPECT TO HARMONICS

(Windings with cyclic coil shift and doubly chorded windings)

The balanced fractional-slot lap windings considered in Appendix 1 were laid out with respect to the main wave, i.e., in such a manner that a maximum distribution factor is obtained for this wave. This layout yields, then, fixed values for the distribution factors of the individual harmonics. Under certain conditions it is desirable to avoid one or a few emf or mmf harmonics. In this case, the winding is to be laid out with respect to this specific harmonic or these specific harmonics.

Two ways are available: first, a cyclic shift of coils from phase to phase within the same repeatable winding part, and, second, a shifting of repeatable winding parts with respect to each other. Both ways will be explained.

A2-1. Cyclic Shift of Coils from One Phase to the Other Within the Same Repeatable Part. Fig. A2-1 shows the slot star of a 3-phase, 20-pole winding with q = 17/5 = 3 2/5. For this winding, N = 17 and d = 5. Furthermore (Eq. A1-5),



+ = Slots assigned to phase A.
□ = Slots assigned to phase C.
○ = Slots assigned to phase B.

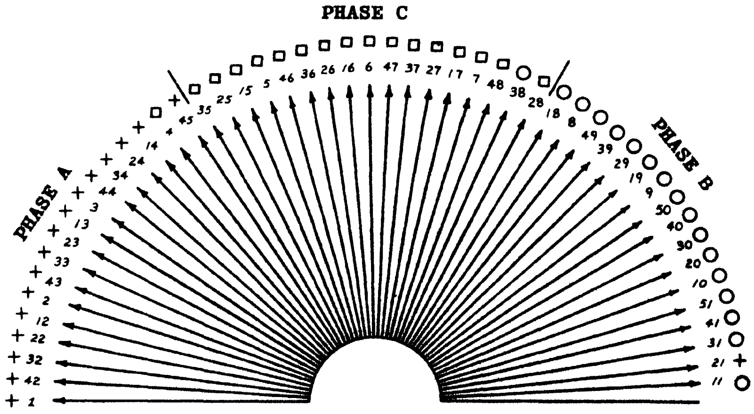
Fig. A2-1. Basic slot star of a 3-phase fractional-slot winding with q = 3 2/5.

$$D = \frac{3 \times 17 \times P + 1}{5} = 41 \quad \text{with } P = 4$$

The slot star comprises $mN = 3 \times 17 = 51$ slots. If the first 17 slots are assigned to phase A, the following 17 slots to phase C, and the last 17 slots to phase B, the layout with respect to the main wave, considered in Appendix 1, is obtained. This type of a layout will be denoted as the basic one, and the layout with cyclic shift of coils will be referred to it, or compared with it. (Note that the slots of phase A are indicated by crosses, those of phase C by rectangles, and those of phase B by circles.)

Fig. A2-2 shows the slot star of Fig. A2-1 but with slots 4, 38, and 21 symmetrically shifted. Slot 4 of phase A is assigned to phase C, slot 38 of phase C is assigned to phase B, and slot 21 of phase C is assigned to phase A. The 3 slots, 4, 38, and 21, all lie next to the last slots of the basic slot star (Fig. A2-1).

The cyclic shift normally aims at such a sequence of the pole-phase groups in each phase that the larger (or smaller) groups are not concentrated but dispersed among the smaller (or larger) groups. Consider phase A of Fig. A2-1. The slots assigned to this phase A are:



+ = Slots assigned to phase A.
☐ = Slots assigned to phase C.
○ = Slots assigned to phase B.

Fig. A2-2. Slot star of the 3-phase winding shown in Fig. A2-1 with one cyclic shift. (Slots 4, 38, and 21 are shifted).

1-2-3-4   12-13-14   22-23-24   32-33-34   42-43-44-45

and the sequence of the pole-phase groups is:

4   3   3   3   4

i.e., all the smaller groups lie together. Consider now the same phase in Fig. A2-2 in which slot 4 is replaced by slot 21. The slots now assigned to this phase are:

1-2-3   12-13-14   21-22-23-24   32-33-34   42-43-44-45

and the sequence of the pole-phase groups is:

3   3   4   3   4

i.e., the concentration of the smaller groups is avoided. This has been achieved by breaking up the first pole-phase group with 4 single coils.

The cyclic shift of coils within the same repeatable part reduces the distribution factors of some of the harmonics and increases the distribution factors of the others. The distribution factor of the main wave is always decreased in comparison with the basic slot distribution. In order to reduce a certain harmonic, several slot sequences, obtained by different cyclic shifts, must be investigated, i.e., the trial-and-error method is to be used.

The cyclic shift which is necessary and possible, in order to avoid concentration of larger or smaller pole-phase groups, can be found by the following method:

(a) Write the D-series for phases A, C, and B one above the other.

(b) Write, for phase A, the d-pole-phase groups as they follow each other in the machine.

(c) Break up a larger pole-phase group in phase A and check whether the slot removed from phase A can be replaced by a slot of phase B or C, lying in the same column, in order to achieve the desired result.

This will be explained by several examples. Note that the D-series of phase C is obtained from that of phase A by adding to all numbers of phase A the number N(D - integer x m) = N or 2N, and that the D-series of phase B is obtained from that of phase C by adding the same number to this latter series.

First example:

As the first example, the winding shown in Fig. A2-1 will be considered. For this winding, N = 17 and D = 41. The number which is to be added to the D-series of phase A, in order to obtain the D-series for phase C, and to the latter D-series, in order to obtain the D-series for phase B, is:

$$17\ (41 - \text{integer} \times 3) = 17\ (41 - 39) = 17 \times 2 = 34$$

The 3 D-series are, therefore:

Phase A...1 42 32 22 12 2 43 33 23 13 3 44 34 24 14 4 45
Phase C..35 25 15 5 46 36 26 16 6 47 37 27 17 7 48 38 28
Phase B..18 8 49 39 29 19 9 50 40 30 20 10 51 41 31 21 11

and the grouping of phase A is:

1-2-3-4 12-13-14 22-23-24 32-33-34 42-43-44-45

There are 3 concentrated smaller groups and 2 larger. In order to avoid the concentration of the smaller groups, one larger group must be broken up, and one smaller group must be converted into a larger.

Starting with the first larger pole-phase groups (slots 1, 2, 3, 4) and removing 4 from it, the slots 38 and 21 can be obtained as substitutes. Slot 38 from phase C does not fit into phase A, because it would make a sixth pole-phase group with a single coil. Slot 21 from phase B gives a 4-coil group with slots 22, 23, and 24 and the grouping becomes:

1-2-3 12-13-14 21-22-23-24 32-33-34 42-43-44-45

as desired. Moving slot 21 from phase B into phase A necessitates the shift of slot 4 from phase A into phase C and of slot 38 from phase C into phase B, as shown in Fig. A2-2, in order that the winding be balanced. The cyclic shift thus made goes clockwise.

If, instead of the first larger pole-phase group of phase A, the second larger group of this phase (slots 42, 43, 44, 45) is broken up, for example, by removing slot 42 from phase A, the slots 25 and 8 are obtained as substitutes. Slot 8 from phase B does not fit into phase A, because it would make a sixth pole-phase group with a single coil. Slot 25 from phase C gives a 4-coil group with slots 22, 23, and 24, and the grouping becomes:

1-2-3-4 12-13-14 22-23-24-25 32-33-34 43-44-45

as desired. Moving slot 25 from phase C into phase A makes it necessary to move slot 42 from phase A into phase B and slot 8 from phase B into phase C, in order that the winding be balanced. The cyclic shift made goes counter-clockwise.

When a cyclic shift goes clockwise, a slot of phase B is substituted for the moved-out slot of phase A, and, when a cyclic shift goes counter-clockwise, a slot of phase C is substituted for the moved-out slot of phase A.

Sometimes more than one cyclic shift leads to the desirable solution. Consider, for example, slot 45 of phase A. If this slot is moved out, slots 28 and 11 are available as substitutes. Slot 28 does not fit into phase A. Slot 11 makes a 4-coil group with slots 12, 13, and 14, but nothing is gained, because again 3 pole-phase groups with 3 single coils each are together, namely, the groups (22, 23, 24), (32, 33, 34), and (42, 43, 44). However, if a second cyclic shift is made by moving out coil 14 from phase A, and substituting for it slot 31, the grouping of phase A becomes:

1-2-3-4 11-12-13 22-23-24 31-32-33-34 42-43-44

as desired. Both cyclic shifts go clockwise.

The more cyclic shifts that are made, the smaller becomes the distribution factor of the main wave. Therefore, the number of cyclic shifts applied, in order to get the desirable grouping, should be as small as possible. However, solutions with different coil groupings in the phase are obtained, when different numbers of cyclic shifts are applied (see the example), and it may happen that the solution with the larger number of shifts reduces the undesirable harmonic more than the solution with the smaller number of shifts.

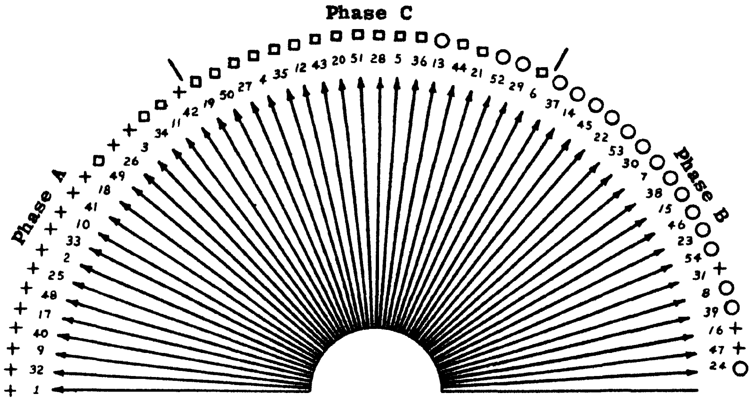
The grouping of only phase A has been examined in the foregoing considerations. If the shift is made symmetrically (cyclic), i.e., by using the same column of the 3 D-series, the results obtained for phase A apply also to the 2 other phases. Symmetrical (cyclic) shifting is necessary in order that the winding be balanced.

Second example:

As the second example, a 3-phase, 14-pole winding with $q = 2\frac{4}{7}$ will be considered. For this winding, N = 18, and

$$D = \frac{3 \times 18 \times P + 1}{7} = 31 \quad \text{with } P = 4$$

Furthermore, N(D - integer x m) = 18 (31 - integer x 3) = 18. The 3 D-series, therefore, are:



+ = Slots assigned to phase A.
☐ = Slots assigned to phase C.
○ = Slots assigned to phase B.

Fig. A2-3. Slot star of a 3-phase fractional-slot winding with $q = 2\ 4/7$, $p = 14$, and 3 cyclic shifts.

Phase A...1 32 9 40 17 48 25 2 33 10 41 18 49 26 3 34 11 42
Phase C..19 50 27 4 35 12 43 20 51 28 5 36 13 44 21 52 29 6
Phase B..37 14 45 22 53 30 7 38 15 46 23 54 31 8 39 16 47 24

and the grouping of phase A is:

1-2-3 9-10-11 17-18 25-26 32-33-34 40-41-42 48-49

Applying 3 clockwise going cyclic shifts, as shown in Fig. A2-3, the following grouping for phase A is obtained:

1-2-3 9-10 16-17-18 25-26 31-32-33 40-41-42 47-48

It has less concentration of larger pole-phase groups than the basic grouping.

A2-2. Shifting of Repeatable Winding Parts with Respect to Each Other (Second Chording). As an example for shifting repeatable parts, the 3-phase, 20-pole winding shown in Fig. A2-1 will be considered. For this winding, $q = 3\frac{2}{5}$, $N = 17$, $d = 5$, and $D = 41$. There are $\frac{20}{5} = 4$ repeatable parts.

The $N = 17$ slots which belong to phase A in the first repeatable part are, for the basic layout:

1 42 32 22 12 2 43 33 23 13 3 44 34 24 14 4 45

The 17 slots which belong to phase A in the second recurrent part are obtained from those in the first part by adding to all numbers of the latter $mN = 3 \times 17 = 51$. Thus the slots belonging to phase A in the second repeatable part are, for the basic layout:

52 93 83 73 63 53 94 84 74 64 54 95 85 75 65 55 96

The angle between 2 consecutive slots (vectors) of the slot star is α_m (see Eq. A1-3). In order to produce a shift of the second recurrent part with respect to the first part equal to an angle $3\alpha_m$, for example, the slots of the second repeatable part assigned to phase A must be (see Fig. A2-4)

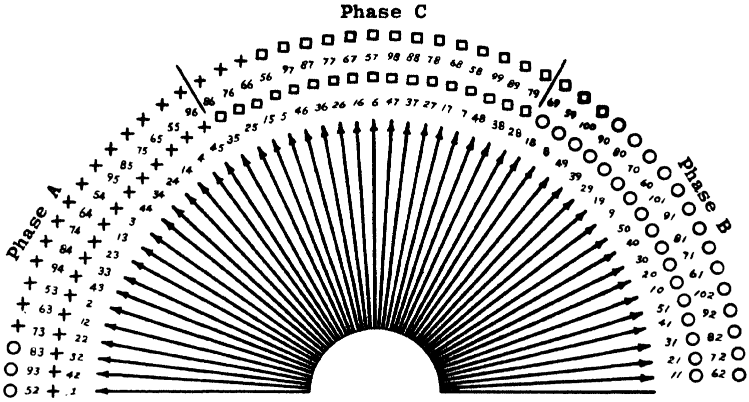
73 63 53 94 84 74 64 54 95 85 75 65 55 96 86 76 66

i.e., the first 3 slots of phase C are to be assigned to phase A, the first 3 slots of phase B are to be assigned to phase C, and the first 3 slots of phase A to phase B. The resultant emf and mmf of the first recurrent part are then shifted by the angle $3\alpha_m$ with respect to the resultant emf and mmf of the second recurrent part.

The normal chording can be considered as a shift of the lower layer with respect to the upper layer. The normal chording makes it necessary to introduce the pitch factor. The shifting of repeatable winding parts with respect to each other has the same effect as the shifting of the lower layer with respect to the upper layer and necessitates the introduction of a second pitch factor. For this reason, the windings with shifting of recurrent parts with respect to each other are called doubly chorded windings.

While the cyclic shift of coils within the same repeatable part changes the distribution factors of the main wave and the harmonics, the shifting of repeatable parts with respect to each other introduces a second pitch factor, which reduces the magnitudes of the main wave and the harmonics without influencing their distribution factors. The windings with the shift of repeatable parts are laid out for maximum distribution factor of the main wave.

The winding of Fig. A2-4 has 4 recurrent winding parts but only 2 of them are shown in the figure. The fourth winding part is to be shifted with respect to the third the same number of angles α_m as the second part is shifted with respect to the first. The first and third parts and the second and fourth parts have then the same position in the slot star, respectively. The shift in Fig. A2-4 is made clockwise. It can also be made counter-clockwise. In this case, for a shift that equals $3\alpha_m$,



+ = Slots assigned to phase A.
□ = Slots assigned to phase C.
○ = Slots assigned to phase B.

Fig. A2-4. Slot star of the 3-phase winding of Fig. A2-1 with the second recurrent part shifted $3\alpha_m$ with respect to the first part.

the last 3 slots of phase A (65, 55, 96) are assigned to phase C, the last 3 slots of phase C (99, 89, 79) are assigned to phase B, and the last 3 slots of phase B (82, 72, 62) are assigned to phase A.

The shifting of repeatable winding parts with respect to each other reduces the maximum possible number of parallel circuits. The winding of Fig. A2-4 can have only 2 parallel paths in each phase, while the basic layout may have 4 parallel paths. When it becomes necessary to reduce several harmonics, the cyclic shift of coils within the same repeatable winding part and the shift of repeatable winding parts with respect to each other can be combined. In this case, first the cyclic shift is to be made and the corresponding slot distribution determined, and then the parts shifted with respect to each other.

APPENDIX 3

BALANCED FRACTIONAL-SLOT WAVE WINDINGS WITH SINGLE AND DOUBLE CHORDING

A3-1. The D-Series and the y-Series. Any fractional-slot winding which can be laid out as a balanced lap winding can also be laid out as a balanced wave winding. Thus, if the conditions for balance of a lap winding, given by Eq. A1-7, are satisfied, the wave winding will be balanced.

The layout of a fractional-slot wave winding is always made with respect to the main wave, i.e., for maximum distribution factor of this wave (see Art. A1-3). The cyclic shift of coils from one phase to the other within the same repeatable part cannot be applied here. The slots belonging to the 3 phases can be obtained either from the slot star or from the D-series by assigning the first N slots ($q = \frac{N}{d}$) to phase A, the following N slots to phase C, and the last N slots to phase B (see Art. A1-3).

With 2 conductors per slot, one in each layer, the slot star shows the position in the magnetic field of not only the slots but of the upper and lower conductors as well. Making at first the assumption that there are only 2 conductors per slot, 2 consecutively connected upper conductors of a lap winding lie in adjacent slots; for example, in slots 1 and 2 or slots 3 and 4, and so on. This is not the case with the wave winding. In the latter, 2 consecutive upper conductors must lie y slot pitches apart, where y is the winding pitch measured in slot pitches, i.e., the consecutive upper (or lower) conductors of the wave winding must follow the y-series

$$1, \quad 1 + y, \quad 1 + 2y, \quad 1 + 3y \; \ldots \qquad (A3\text{-}1)$$

The slots assigned to a phase follow the D-series, and their sequence around the machine must follow the y-series. The problem of laying out a balanced wave winding consists in the co-ordination of the D-series and the y-series of the winding.

A3-2. The Winding Pitch. The winding pitch must be equal to approximately 2 pole pitches. With 2 conductors per slot, the number of upper (or lower) conductors in d pole pitches is mN, and the winding pitch must deviate from $\frac{mN}{d/2}$, i.e., it must be

$$y = \frac{2mN + a}{d} \qquad \text{(A3-2)}$$

where a is the smallest integer which makes y an integer; a can be positive or negative. It will be shown in the next Article that the magnitude of a determines the kind of co-ordination of the D-series and y-series and through it the number of winding parts in each phase. Furthermore, it will be shown that the sign of a determines whether the winding goes in the same direction as the numbering of the slots (cw) or opposite to it (ccw).

Eq. A3-2 can be written as (see Eq. A1-1)

$$y = \frac{2mN + a}{d} = 2mq + \frac{a}{d} = 2mI + 2m\frac{n}{d} + \frac{a}{d} \qquad \text{(A3-2a)}$$

For 3-phase windings,

$$y = 6I + \frac{6n + a}{d} \qquad \text{(A3-3)}$$

Since y must be an integer, then $\frac{(6n + a)}{d}$ must be an integer, i.e., the magnitude and sign of a do not depend upon the integral part of q but only upon the fraction $\frac{n}{d}$. As an example, a will be the same for $q = 1\frac{1}{5}, 2\frac{1}{5}, 3\frac{1}{5}, \ldots$ Table 7-44 gives the magnitudes and signs of a for different fractions $\frac{n}{d}$.

The winding pitch y is to be divided into the back pitch y_b and front pitch y_f, so that $y = y_b + y_f$.

A3-3. Layout of a Singly Chorded, Balanced, Fractional-slot Wave Winding. As in the balanced fractional-slot lap winding, the number of repeatable windings parts is $\frac{p}{d}$ (Eq. A1-7); therefore, the number of slot stars is also $\frac{p}{d}$.

Due to the fact that each $\frac{p}{2}$ coils of the wave winding go around the whole rotor or stator, the consideration of the wave winding cannot be limited to one repeatable part but must comprise all $\frac{p}{d}$ repeatable parts. This means that in the case of the wave winding all $\frac{p}{d}$ slot stars, or, what is the same, all $\frac{p}{d}$ D-series, must be considered simultaneously. If the slots of the winding are numbered by consecutive digits, the slot star of the second repeatable part is obtained from the slot-star of the first repeatable part by adding the quantity mN to all numbers of the latter slot star. The same applies to the D-series. When the first D-series is set up, the second D-series is obtained by adding mN to the numbers of the first series, the third by adding mN to the numbers of the second D-series, and so forth. The

$\frac{p}{d}$ D-series represent the upper (or lower) conductors of the whole winding.

The vectors of the $\frac{p}{d}$ slot stars coincide, i.e., if the D-series are written one above the other, the $\frac{p}{d}$ conductors which lie in the same column are in phase and can be substituted one for the other. This fact makes it possible to lay out balanced wave windings.

The method of laying out a balanced, fractional-slot, singly chorded wave winding and the influence of the magnitude and sign of a (Eq. A3-2) will be demonstrated by several examples.

(a) $a = +1$.

It follows from Eqs. A1-4 and A3-1 that in this case $y = D$, i.e., the y-series and the D-series are identical. Therefore, the winding can be made up by using the consecutive vectors of the slot star or their in-phase vectors, or what is the same, by using the consecutive numbers of the $\frac{p}{d}$ D-series.

The 3-phase winding shown in Fig. A3-1 is an example for $a = +1$. For this winding $q = 1\frac{4}{5}$, $N = 9$, $d = 5$. From Eq. A1-5

$$D = \frac{3 \times 9 \times P + 1}{5} = 11 \quad \text{with } P = 2$$

and from Eq. A3-2

$$y = \frac{6 \times 9 + a}{5} = 11 = D \text{ with } a = +1$$

Assuming that the machine has 10 poles, there are $\frac{10}{5} = 2$ D-series. They are, for phase A,

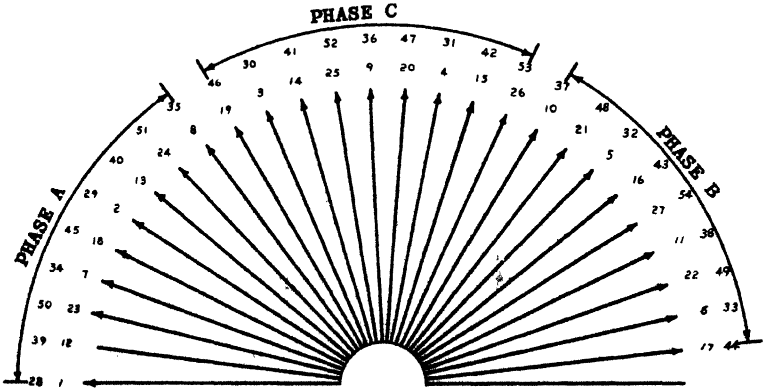


Fig. A3-1. Slot star of a 3-phase fractional-slot winding with q = 1 4/5 and p = 10, showing the position of the vectors of the 2 D-series.

1	12	23	7	18	2	13	24	8	D-series
28	39	50	34	45	29	40	51	35	

Hence the 2 y-series, i.e., the 2 winding parts of phase A, are

1	12	23	34	45	2	13	24	35	y-series
28	39	50	7	18	29	40	51	8	

In setting up the y-series, use has been made of the fact that conductors lying in the same column are in phase and can be substituted for each other. The winding progresses clockwise, i.e., with the numbering of the slots since a is positive.

(b) $a = -1$.

In this case, $y = mN - D$ and the y-series will be found in the slot star or the D-series running opposite to the numbering of the slots. Consider a 10-pole, 3-phase winding with $q = 2\frac{1}{5}$. For this winding $N = 11$, $d = 5$, and

$$D = \frac{33 \times P + 1}{5} = 20 \text{ with } P = 3$$

$$y = \frac{6 \times 11 + a}{5} = 13 \text{ with } a = -1$$

$$y = mN - D = 33 - 20 = 13$$

The D-series of this winding, for phase A, are

1	21	8	28	15	2	22	9	29	16	3	D-series
34	54	41	61	48	35	55	42	62	49	36	

Considering these series, the y-series is found going from the right to the left. For example, in the first D-series,

$$3, \quad 3 + 13 = 16$$
$$16 + 13 = 29$$
$$29 + 13 = 42 - mN = 9 \ldots$$

This winding progresses counter-clockwise, since a is negative. The 2 y-series, i.e., the 2 winding parts of phase A, are

1	54	41	28	15	2	55	42	29	16	3	y-series
34	21	8	61	48	35	22	9	62	49	36	

(c) $a = +2$.

In this case, $y = 2D$ and the y-series is represented by the alternate numbers of the D-series. This leads to twice as many parts in each phase as for the case $a = \pm 1$. The winding progresses clockwise, since a is positive. Consider a 10-pole, 3-phase winding with $q = 3\frac{3}{5}$. For this winding $N = 18$, $d = 5$, and

$$D = \frac{54 \times P + 1}{5} = 11 \text{ with } P = 1$$

$$y = \frac{6 \times 18 + a}{5} = 22 \text{ with } a = +2$$

$$y = 2D = 22$$

The D-series of this winding for phase A, are

1 12 23 34 45 2 13 24 35 46 3 14 25 36 47 4 15 26
55 66 77 88 99 56 67 78 89 100 57 68 79 90 101 58 69 80
D-series

The 4 y-series, i.e., the 4 winding parts of phase A, are

1 23 45 67 89 3 25 47 69
12 34 56 78 100 14 36 58 80
55 77 99 13 35 57 79 101 15
66 88 2 24 46 68 90 4 26
y-series

The first and second winding parts are not in phase and must be connected in series. The same applies to the third and fourth winding parts. When N is odd, the first and third winding parts have one coil more than the second and fourth winding parts.

(d) $a = -2$ and $a > 2$.

In the case $a = -2$, $y = 2(mN-D)$, the y-series is represented, as in the case $a = +2$, by the alternate numbers of the D-series. However, in this case, the y-series runs opposite to the D-series, similar to the case $a = -1$, and the winding progresses counter-clockwise. Also, when $a > 2$, the winding progresses clockwise when a is positive, and counter-clockwise when a is negative. In general, for any value of a, the number of parts of each phase is $\frac{p}{d} \times a$.

The assumption has been made that there are only 2 conductors per slot. If the number of conductors per slot is larger than 2, the winding can be considered as one having a number of slots equal to the actual number of slots times the number of conductors per slot per layer. This makes each slot have only 2 conductors and the rules for laying out the wave winding given above can be applied (see Art. 7-1). Further information on the layout of balanced fractional-slot wave windings and more examples are given in Arts. 7-4 to 7-13.

The fractional-slot wave windings explained above are balanced and have the same emf- and mmf-curves as the corresponding fractional-slot lap windings because the same slots are assigned to the 3 phases in both kinds of windings. Also, the maximum possible number of parallel paths is the same as for the fractional-slot lap windings.

Comparing the wave windings explained here with the modified d-c windings treated in Chapter 6, the latter have only 2 winding parts per phase independent of the number of poles. The number of winding parts per phase of the windings considered here depends upon the magnitude of a. On the other hand, the modified d-c windings have abnormal-front pitches after each $\frac{p}{2}$ coils, while in the windings considered here all coils have equal-front pitches.

A3-4. Doubly Chorded Balanced Fractional-slot Wave Windings. The shifting of repeatable winding parts with respect to each other, as explained in Art. A2-2 for the fractional-slot lap windings, can be applied also to fractional-slot wave windings. This is due to the fact that the latter windings are laid out in the same manner as the fractional-slot lap windings with maximum distribution factor of the main wave (see Art. A3-1).

As mentioned in Art.A2-2, the shifting of repeatable parts, i.e., the second chording, is made in order to reduce undesirable harmonics. The even parts (2, 4...) are moved with respect to the odd parts (1, 3...) by a certain number of consecutive vectors of the slot star, i.e., by a certain number of magnetic field angles α_m (Eq. A1-3). This number of angles α_m will be designated by **k**. The cases a = ± 1 and a = ± 2 (see Eq. A3-2) will be considered. As in the case of the singly chorded windings (Art. A3-3), the magnitude of a determines the number of winding parts (waves) in each phase, and the sign of a determines whether the winding progresses clockwise or counter-clockwise.

(a) a = ± 1.

In order to lay out a doubly chorded winding for this case, the following rules are to be followed:

1. Apply the 5 rules (a to e) given in Art. 7-9 for singly chorded windings with a = ± 1.
2. Determine also for phases C and B the $\frac{p}{d}$ y-series, i.e., the conductors belonging to the $\frac{p}{d}$ waves, one wave above the other.
3. Add k conductors following the y-series to the end of the first wave of phase A.

4. Omit k conductors at the beginning of the second wave of phase A.
5. Consider the first 2 waves for phase C. If the k conductors added to the first wave of phase A lie in the second wave of phase C, then treat the first 2 waves of phase C in the same manner as those of phase A. On the other hand, if the k conductors added to the first wave of phase A lie in the first wave of phase C, then k conductors are to be added to the end of the second wave and subtracted from the beginning of the first wave.
6. Consider phase B and treat it with respect to phase C in the same manner as phase C has been treated under (5) with respect to phase A.
7. Wind, in each wave pair, first the N + k conductors of the larger wave and connect by a reversing jumper the last conductor of this wave with the last conductor of the smaller wave consisting of N - k conductors. Then wind the latter wave in a direction opposite to that of the larger wave.

The total number of waves in each phase is $\frac{p}{d}$. Since the waves are connected by pairs in series, the maximum number of parallel circuits is $\frac{p}{2d}$, i.e., half of the number of parallel circuits of the singly chorded wave windings.

The procedure will be demonstrated with the 3-phase, 10-pole winding with $q = 2\frac{1}{5}$ considered under (b) in Art. A3-3. The winding progresses counter-clockwise, for a = - 1. The y-series of both repeatable parts are for phase A

1	54	41	28	15	2	55	42	29	16	3	y-series
34	21	8	61	48	35	22	9	62	49	36	

for phase C

23	10	63	50	37	24	11	64	51	38	25	y-series
56	43	30	17	4	57	44	31	18	5	58	

and for phase B

12	65	52	39	26	13	66	53	40	27	14	y-series
45	32	19	6	59	46	33	20	7	60	47	

The 2 waves of each phase will be shifted with respect to each other by k = 3 angles α_m. The waves of the 3 phases become

1 54 41 28 15 2 55 42 29 16 3 56 43 30
61 48 35 22 9 62 49 36 phase A

23 10 63 50 37 24 11 64 51 38 25 12 65 52
17 4 57 44 31 18 5 58 phase C

39 26 13 66 53 40 27 14 phase B
45 32 19 6 59 46 33 20 7 60 47 34 21 8

Corresponding to k = 3, 3 conductors (56, 43, 30) are added at the end of the first wave of phase A. These 3 conductors follow the y-series (3 + 66 - 13 = 56, 56 - 13 = 43, 43 - 13 = 30). In phase C these 3 conductors lie in the second wave, and, therefore, to the end of the first wave of phase C 3 conductors also are added (12, 65, 52). Since 3 conductors are added to the ends of the first waves of phases A and C, 3 conductors are omitted at the beginnings of their second waves (34, 21, 8, and 56, 43, 30 respectively). Considering phase B, the 3 slots (12, 65, 52) added to the end of the first wave of phase C lie in the first wave of this phase. Therefore, 3 slots (34, 21, 8) are added to the end of the second wave of phase B, and 3 slots are omitted at the beginning of its first wave.

If it is assumed that $y_b = 6$ and $y_f = 7$ and that the y-series represent lower conductors, then, in phase A, lower conductor 30 is connected to upper conductor 24 and lower conductor 36 is connected to upper conductor 30. Upper conductors 24 and 30 are to be connected by a reversing jumper, and the smaller wave is wound opposite to the larger wave. The same applies to the 2 other phases.

(b) $a = \pm 2$.

Since in this case the y-series are represented by alternate numbers of the D-series, each phase consists of 2 parts and each part of $\frac{p}{d}$ waves. Each part is to be treated separately. The smallest shift of the y-series with respect to each other is here $2 \times \alpha_m$, i.e., the shift angle is twice the value of k. The following rules must be followed for the layout of this winding:

1. Apply the 6 rules (a to f) given in Art. 7-10 for singly chorded windings with $a = \pm 2$.
2. Determine also for phase C and B the $\frac{p}{d}$ y-series of both windings.
3. Write for the 3 phases, separately, the $\frac{p}{d}$ y-series of the first winding part.

4. Apply rules 3, 4, 5, and 6 given for the case $a = \pm 1$.
5. Connect in pairs the longer and shorter waves, the number of conductors of which differ by 2k, by reversing jumpers.
6. Repeat the same for the second winding part.

The maximum possible number of parallel paths is, as for the case $a = \pm 1$, $\frac{p}{2d}$, i.e., half of the number of parallel paths of the singly chorded winding.

As an example, a 3-phase, 10-pole winding with $q = 2\frac{2}{5}$ will be considered. For this winding N = 12, d = 5, and from Eqs. A1-5 and A3-2

$$D = \frac{3 \times 12 \times P + 1}{5} = 29 \text{ with } P = 4$$

$$y = \frac{6 \times 12 + a}{5} = 14 \text{ with } a = -2$$

The $\frac{p}{d} = 2$ D-series of phase A are

1	30	23	16	9	2	31	24	17	10	3	32	D-series
37	66	59	52	45	38	67	60	53	46	39	68	

and the $\frac{p}{d} \times a = 4$ waves, i.e., the 4 y-series of phase A, are

1	59	45	31	17	3	y-series of the first winding part
37	23	9	67	53	39	

30	16	2	60	46	32	y-series of the second winding part
66	52	38	24	10	68	

Accordingly for phase C

25	18	11	4	33	26	19	12	5	34	27	20	D-series
61	54	47	40	69	62	55	48	41	70	63	56	

25	11	69	55	41	27	y-series of the first winding part
61	47	33	19	5	63	

18	4	62	48	34	20	y-series of the second winding part
54	40	26	12	70	56	

and for phase B

13	6	35	28	21	14	7	36	29	22	15	8	D-series
49	42	71	64	57	50	43	72	65	58	51	44	

13	71	57	43	29	15	y-series of the first winding part
49	35	21	7	65	51	

6	64	50	36	22	8	y-series of the second winding part
42	28	14	72	58	44	

The waves of both winding parts for a shift k = 2 (= 4 α_m) are

First winding part

A	1	59	45	31	17	3	61	47
			9	67	53	39		
C	25	11	69	55	41	27	13	71
			33	19	5	63		
B			57	43	29	15		
	49	35	21	7	65	51	37	23

Second winding part

A	30	16	2	60	46	32	18	4
			38	24	10	68		
C			62	48	34	20		
	54	40	26	12	70	56	42	28
B	6	64	50	36	22	8	66	52
			14	72	58	44		

The 2 winding parts of each phase are out of phase and must be connected in series (see Art. 7-10). No parallel circuits are possible for the winding considered.

APPENDIX 4

UNBALANCED, FRACTIONAL-SLOT LAP AND WAVE WINDINGS

The unbalanced windings are laid out for a minimum unbalance and maximum distribution factor of the main wave.

There are 2 conditions for balance (see Art. A1-5) and, therefore, 2 kinds of unbalance. A winding is always unbalanced when the number of slots is not divisible by the number of phases, i.e., $\frac{S}{m} \neq$ integer ($\frac{p}{d} \neq$ integer). A winding is also unbalanced when the number of slots is divisible by the number of phases, if the number of poles in a recurrent winding part is divisible by the number of phases, i.e., $\frac{d}{m}$ = integer. In the first case, 1 or 2 coils are to be left out in order to make the number of coils equal for all phases.

The second kind of unbalance, i.e., the case when $\frac{d}{m}$ = integer and $\frac{S}{m}$ = integer, will be considered first.

In the balanced, fractional-slot windings, the slots of d poles are represented by a single, half-circle slot star. This is not the case with the unbalanced windings. Also, Eq. A1-5, which is fundamental for the balanced fractional-slot windings, is not applicable for the unbalanced windings.

A4-1. Unbalanced, Fractional-slot Lap Windings with $\frac{S}{m}$ = Integer and $\frac{d}{m}$ = Integer. As an example, a 3-phase, 12-pole winding with 42 slots will be considered. For this winding, $q = \frac{7}{6}$, $N = 7$, $d = 6$. The angle between 2 slots is (Eq. A1-2):

$$\alpha_S = \frac{180 \times 6}{3 \times 7} = 51\tfrac{3}{7}^{\circ}$$

Using slot 1 as reference, the angles between this slot and the 20 successive slots lying in d = 6 poles are

1	2	3	4	5	6	7	8	9	10	11 ...
0	$51\frac{3}{7}$	$102\frac{6}{7}$	$154\frac{2}{7}$	$205\frac{5}{7}$	$257\frac{1}{7}$	$308\frac{4}{7}$	360	$51\frac{3}{7}$	$102\frac{6}{7}$	$154\frac{2}{7}$ ...

Disregarding the angle of 180° for the same reason as that given for balanced, fractional-slot lap windings (Art. A1-2), the angles become

1	2	3	4	5	6	7	8	9	10	11	12
0	$51\frac{3}{7}$	$102\frac{6}{7}$	$154\frac{2}{7}$	$25\frac{5}{7}$	$77\frac{1}{7}$	$128\frac{4}{7}$	0	$51\frac{3}{7}$	$102\frac{6}{7}$	$154\frac{2}{7}$	$25\frac{5}{7}$ ...

It can be seen that only N slots make a half-circle slot star, in contrast to the balanced, fractional-slot lap winding in which mN slots make the half-circle slot star. The mN slots which lie in d poles do not make a single star but m slot stars with N slots in each. Slots (1, 1 + N, 1 + 2N), slots (2, 2 + N, 2 + 2N) and so on, are in-phase slots, respectively. Fig. A4-1 shows the three slot stars of the winding considered.

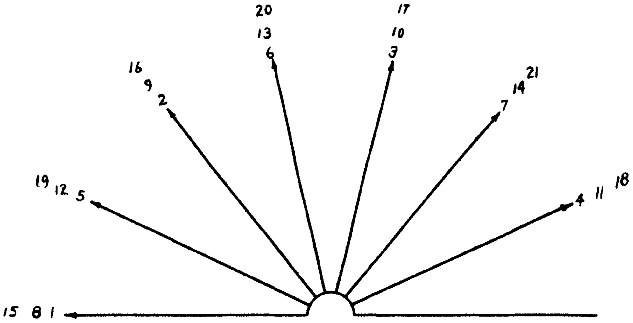


Fig. A4-1. Slot star of an unbalanced, fractional-slot, 3-phase winding with q = $1\frac{1}{6}$ ($\frac{S}{m}$ = integer)

The magnetic-field angle is

$$\alpha_m = \frac{180^\circ}{N} \tag{A4-1}$$

and the ratio α_s/α_m is

$$\alpha_s/\alpha_m = d/m \tag{A4-2}$$

i.e., between 2 vectors which correspond to 2 adjacent slots in the machine lie ($\frac{d}{m}$ -1) other vectors. In the example, $\frac{d}{m} = \frac{6}{3} = 2$ and between slots 1 and 2, 2 and 3, and so on, lies one other vector.

As in balanced, fractional-slot lap windings, the vectors of all 3 slot stars follow a certain D-series. For the winding of the example, this is

$1,\ 1 + 4 = 5,\ 1 + (2 \times 4 - N) = 2,\ 1 + (3 \times 4 - N) = 6 \ldots$

The value of D which is here equal to 4 can be found by the same consideration as that applied to balanced windings (Art. A1-2). It is true that

$$D \times \alpha_s = 180 \times P + \alpha_m$$

Inserting α_s from Eq. A1-2 and α_m from Eq. A4-1, there results

$$D = \frac{mNP + m}{d} \qquad (A4\text{-}3)$$

where P is the smallest integer, including zero, which makes D an integer. P becomes zero when d = m.

With the magnitude of D determined, the D-series can be calculated. There are m D-series in d poles, corresponding to the m slot stars in d poles.

For the winding of the example (Fig. A4-1), the m = 3 D-series are

	A		C		B		
1	5	2	6	3	7	4	
8	12	9	13	10	14	11	D-series for d = 6 poles
15	19	16	20	17	21	18	

Each consecutive D-series is obtained from the foregoing series by adding N (here N = 7) to the number of the latter series. The m slots which lie in the same column are in-phase slots.

Maximum distribution factor for the main wave will be obtained when the mN slots represented by the m (here m = 3) series are divided into m parts in such a manner that each part, i.e., each phase, contains N slots and these N slots are as close to one another as possible.

One of the many ways to divide the slots among the 3 phases, for the winding of the example, is indicated by the broken lines. The numbers of single coils assigned to the 3 phases in the 3 D-series are

A	C	B
3	2	2
2	3	2
2	2	3

Also one of the following combinations can be used

A	C	B	A	C	B	A	C	B	
2	3	2	2	2	3	3	2	2	
3	2	2	2	3	2	2	2	3	and so forth
2	2	3	3	2	2	2	3	2	

All these combinations are identical so far as the unbalance is concerned, i.e., they all have the same differences between the amplitudes of the emf's and mmf's and also the same errors in the angles between the emf's and mmf's. However, the coil grouping, i.e., the sequence of larger and smaller pole-phase groups, is not the same for all combinations.

The coil grouping which corresponds to the combination indicated by the broken lines is, for d = 6 poles

2 1 1 1 1 1 1 2 1 1 1 1 1 1 2 1 1 1
A C B A C B A C B A C B A C B A C B

The coil grouping thus obtained applies to d poles. The total winding consists of $\frac{p}{d}$ repetitions of this grouping; consequently, the maximum possible number of parallel circuits is $\frac{p}{d}$. This is the same as for the balanced fractional-slot lap winding. As for the latter, only d poles are to be considered.

The equation (see Eq. A1-1)

$$q = I + \frac{n}{d} \tag{A4-4}$$

also means that each phase has, in d poles, n pole-phase groups with (I + 1) single coils and (d - n) pole-phase groups with I single coils.

In the winding of the example, I = 1, n = 1, d = 6, and each phase has, in d = 6 poles, n = 1 pole-phase group with (I + 1) = 2 single coils and (d - n) = 6 - 1 = 5 pole-phase groups with I = 1 single coil.

The simplifications in the layout and tabulation of balanced fractional-slot lap windings (Art. A1-3) apply only in part to the windings considered here. The sequence of the larger and smaller pole-phase groups is independent of the magnitude of I (Eq. A4-4) just as for the balanced windings. However, the coil grouping obtained for d poles does not represent a repetition of m equal parts and the consideration of the distribution of only d pole-phase groups, as was done for the balanced winding, will not suffice. For the windings treated here, all m x d pole-phase groups of d poles are a unit which repeats $\frac{p}{d}$ times.

The rules given in Arts. 5-4 and 5-6 for the layout of unbalanced fractional-slot lap windings with $\frac{S}{m}$ = integer and $\frac{d}{m}$ = integer and the coil grouping Tables 5-1 and 5-2 were derived on the basis of the foregoing considerations.

A4-2. Unbalanced, Fractional-slot Lap Windings with $\frac{S}{m} \neq$ Integer. When $\frac{S}{m}$ is not equal to an integer, $\frac{d}{m}$ is an integer, and therefore both conditions for balance are not satisfied. In the case in which $\frac{S}{m} \neq$ integer, the whole winding is to be considered instead of only d poles.

If t is the common divisor of the total number of slots S and the number of poles p, then there are t winding parts which have the same position in the magnetic field and, therefore, t slot stars with $\frac{S}{t}$ slots in each. t may be equal to 1.

If (see Eq. A1-1)

$$q = \frac{S}{mp} = \frac{N}{d} \tag{A4-5}$$

where S is not divisible by m, S and p have a common divisor t, and N and d have no common divisor, then

$$S = N \times t \text{ and } mp = d \times t$$

or

$$N = \frac{S}{t} \tag{A4-6}$$

Since there are $\frac{S}{t} = N$ slots in the half-circle slot star, the magnetic field angle is

$$\alpha_m = \frac{180^o}{S/t} = \frac{180^o}{N} \tag{A4-7}$$

The ratio α_s/α_m is

$$\alpha_s/\alpha_m = \frac{d}{m} \quad . \tag{A4-8}$$

i.e., between 2 vectors which correspond to 2 adjacent slots in the machine lie $(\frac{d}{m} - 1)$ other vectors.

Eq. A4-7 is the same as Eq. A4-1 which applies to unbalanced fractional-slot lap windings with $\frac{S}{m}$ = integer and $\frac{d}{m}$ = integer. This leads to the same equation for D as is true for the latter unbalanced windings (Eq. A4-3),

$$D = \frac{mNP + m}{d} \tag{A4-9}$$

where P is the smallest integer including zero which makes D an integer.

There are t D-series for the whole winding with N slots in each. Each consecutive D-series is obtained from the foregoing series by adding N to the numbers of the latter series. The t slots which lie in the same column are in-phase slots.

Maximum distribution factor of the main wave again is obtained when the slots represented by the t D-series are divided into m parts in such a manner that each part, i.e., each phase, contains the same number of slots and that the slots of each phase are as close to one another as possible. Since S is not divisible by m, equal numbers of slots in each phase can be achieved only when a certain number of coils (which is usually smaller than m) is left out. The division of the S slots among the m phases does not necessarily give the same number of larger and smaller pole-phase groups for each phase. The sequence of the larger and smaller pole-phase groups depends upon the layout of the winding and the number and location of the omitted coils.

Note further that the conclusions about the numbers of larger and smaller pole-phase groups drawn from Eq. (A4-4) for balanced fractional-slot lap windings and unbalanced windings with $\frac{d}{m}$ = integer do not apply here.

The rules given in Arts. 5-5 and 5-6 for the layout of unbalanced, fractional-slot lap windings with $\frac{S}{m} \neq$ integer, and the coil grouping Tables 5-5 and 5-6 were derived on the basis of maximum distribution factor of the main wave and minimum unbalance.

Information on the possible number of parallel circuits is given in Art. 5-5.

A4-3. Comparison Between the Balanced and Unbalanced Lap Windings. In the following tabulation, the main features of the balanced and unbalanced lap windings are compared on the basis of the considerations of Appendix 1 and Arts. A4-1 and A4-2.

	Balanced (App. 1)	Unbalanced with S/m = integer (Art. A4-1)	Unbalanced with S/m ≠ integer (Art. A4-2)
Number of slot stars = Number of D-series	p/d	m(p/d)	t = common divisor of S and p
Number of slots in each slot star = Number of slots in each D-series	mN	N	N
Number of repeatable winding parts = Maximum number of parallel circuits	p/d	p/d	Depending upon the layout of the winding and the number and location of the omitted coils. Maximum = t.

	Balanced (App. 1)	Unbalanced with S/m = integer (Art. A4-1)	Unbalanced with S/m ≠ integer (Art. A4-2)
Sequence of larger and smaller pole-phase groups	depends upon n/d	depends upon n/d	Depends upon the layout of the winding and the number and location of the omitted coils.
α_m	$\frac{180}{mN}$	$\frac{180}{N}$	$\frac{180}{N}$
$\frac{\alpha_s}{\alpha_m}$	d	d/m	d/m
Number of vectors which lie in the slot star between 2 adjacent slots = Number of digits which lie in the D-series between 2 consecutive digits.	d - 1	$\frac{d}{m} - 1$	$\frac{d}{m} - 1$
D =	$\frac{mNP + 1}{d}$ P = 1,2, 3...	$\frac{mNP + m}{d}$ P = 0,1,2...	$\frac{mNP + m}{d}$ P = 0,1,2...
Difference between 2 digits lying in the same column of 2 consecutive D-series	mN	N	N

A4-4. Unbalanced, Fractional-slot Wave Windings with $\frac{S}{m}$ = Integer and $\frac{d}{m}$ = Integer. The unbalanced wave windings are derived from the unbalanced lap windings in a manner similar to that by which the balanced wave windings are derived from the balanced lap windings. The same D-series, i.e., the same value of D, applies to balanced lap and wave windings, and this is true also for the unbalanced lap and wave windings. Thus Eq. A4-3 applies to the unbalanced wave windings.

As for the unbalanced lap windings with $\frac{S}{m}$ = integer, there are also a total of $m \times (\frac{p}{d}) = \frac{S}{N}$ D-series with N slots (or upper or lower conductors, see Arts. A3-1 and A3-3) in each. In the unbalanced wave windings, all $m \times (\frac{p}{d})$ D-series must be considered simultaneously, i.e., all slots of the machine are to be considered at the same time. This is in contrast with the balanced wave winding where only all the $\frac{p}{d}$ series of a single phase are treated at a time.

After the $m \times (\frac{p}{d}) = \frac{S}{N}$ D-series with N slots each have been set up on the basis of Eq. A4-3, the y-series must be derived and the S slots divided among the m phases. The kind of division of the slots depends upon the magnitude of a.

Eq. A3-2 for the winding pitch, y, applies also to the unbalanced wave windings. The following considerations will be limited to $d = 3$, 6, and 9. Eq.A3-2 yields for $d = 3$ and $d = 6$, $a = 0$, and for $d = 9$, $a = \pm 3$. Furthermore,

$$\begin{array}{lll} y = 2N & \text{for } d = 3 & (a = 0) \\ y = N & \text{for } d = 6 & (a = 0) \\ y = D & \text{for } d = 9 \text{ and } a = +3 & \\ y = N-D & \text{for } d = 9 \text{ and } a = -3 & \end{array} \qquad \text{(A4-10)}$$

Consecutive D-series differ from each other by N and consecutive slots in each D-series differ from each other by D. Therefore, when $d = 3$, alternate slots of the vertical rows of the D-series follow the y-series; when $d = 6$, consecutive slots of the vertical rows of the D-series follow the y-series; and, when $d = 9$, consecutive slots of the horizontal rows of the D-series follow the y-series.

In the cases $d = 3$ and $d = 6$, $a = 0$. This is the same as when q is equal to an integer. Therefore, in these cases the wave winding is to be made up in the same way as when q = integer, i.e., with abnormal-front pitches and 2 waves in each phase regardless of the number of poles. It is shown in Art. 8-5 that, when $d = 3$, it is preferable to wind continuously and divide the total number of slots (or upper or lower conductors) into 6 equal parts, assigning the first and fourth parts to phase A, and second and fifth parts to phase C, and the third and sixth parts to phase B. The same applies to the case $d = 6$; however, here the parts 1, 3, 5 are not equal to the parts 2, 4, 6 (see Art. 8-6).

When $d = 9$, the $m \times (\frac{p}{d}) = \frac{S}{N}$ y-series with N slots in each are to be derived from the $m \times (\frac{p}{d}) = \frac{S}{N}$ D-series, and the y-series are to be divided into m parts in such a manner that the slots belonging to each phase are as close as possible to one another, thus yielding the maximum distribution factor for the main wave. Each phase consists of $(\frac{p}{d})$ x a waves (see Art. 8-7).

Rules for laying out unbalanced, fractional-slot wave windings with $\frac{S}{m}$ = integer and illustrative examples are given in Chapter 8.

A4-5. Unbalanced Fractional-slot Wave Windings with $\frac{S}{m} \neq$ Integer. Eqs. A4-7 and A4-9 apply also to the unbalanced wave windings with $\frac{S}{m} \neq$ integer. The values of a and y are the same for these windings as for the unbalanced wave windings with $\frac{S}{m}$ = integer (Eq. A4-10).

Since a = 0 for d = 3 and d = 6, the windings are to be made up in these cases as for integral-slot windings in the manner described in Art. A4-4.

As an example, a 3-phase, 8-pole winding with $q = 2\frac{1}{6}$ and 2 conductors per slot will be considered. For this winding N = 13, d = 6, S = 52, t = 4

$$D = \frac{3 \times 13 \times P + 3}{6} = 7 \text{ with } P = 1$$

$$y = \frac{2 \times 3 \times 13 + a}{6} = 13 = N \;(a = 0)$$

There are $t = \frac{S}{N} = \frac{p}{d}\,m = \frac{52}{13} = \frac{8}{6} \times 3 = 4$ D-series with $\frac{S}{t} = N = 13$ slots in each. These series are

	A				C				B			A	
1	8	2	9	3	10	4	11	5	12	6	13	7	
14	21	15	22	16	23	17	24	18	25	19	26	20	D-series
27	34	28	35	29	36	30	37	31	38	32	39	33	
40	47	41	48	42	49	43	50	44	51	45	(52)	46	

One coil is to be left out in order to make the number of coils (upper or lower conductors) the same for all 3 phases. Each phase will have $\frac{51}{3}$ = 17 slots, i.e., 9 slots in one wave and 8 slots in the other. Winding continuously, the 6 waves are

1	14	27	40	2	15	28	41			phase A
7	20	33	46	8	21	34	47	9		
3	16	29	42	4	17	30	43			phase C
22	35	48	10	23	36	49	11	24		
5	18	31	44	6	19	32	45			phase B
37	50	12	25	38	51	13	26	39	(52)	

Long-front pitches appear between conductors 40 and 2, 46 and 8, 47 and 9, 42 and 4, and so on. Two parallel circuits are not possible. The broken lines in the D-series show that the slots assigned to the 3 phases are close to one another.

The circle indicates the slot in which one coil side (one conductor) is omitted. This is slot 52, i.e., the last conductor of the second wave of phase B is left out. As shown in Art. A4-6, the error in magnitude of this distribution is very small (0.3%) and the errors in angle are $-1^\circ\ 20'$ for phase C and $-2^\circ\ 40'$ for phase B. The errors in the angles can be reduced to $-18'$ for phase C and $-1^\circ\ 21'$ for phase B, if the conductor is omitted from slot 51 (instead of slot 52) which lies in the middle of the second wave of phase B. The error in magnitude is the same as before.

When $d = 9$, a is equal to $= \pm 3$. The common divisor t, of S and p, equal to $\frac{S}{N}$, determines the number of D-series with N slots in each. As in the case $\frac{S}{m}$ = integer (Art. A4-4), $t = \frac{S}{N}$ y-series are to be derived from the D-series and divided among the phases. This will be explained by an example of a 3-phase, 12-pole winding with $q = 1\frac{2}{9}$ and 2 conductors per slot. For this winding, $N = 11$, $d = 9$, $S = 44$, $t = \frac{S}{N} = 4$. Furthermore,

$$D = \frac{3 \times 11 \times P + 3}{9} = 4$$

$$y = \frac{2 \times 3 \times 11 + a}{9} = 7 = N - D \quad (a = -3)$$

The $t = 4$ D-series are

1	5	9	2	6	10	3	7	11	4	⑧	D-series
12	16	20	13	17	21	14	18	22	15	19	
23	27	31	24	28	32	25	29	33	26	㉚	
34	38	42	35	39	43	36	40	44	37	41	

Since $a = -3$, the winding goes counter-clockwise. The $t = 4$ y-series are

1	38	31	24	17	10	3	40	33	26	19	y-series
12	5	42	35	28	21	14	7	44	37	㉚	
23	16	9	2	39	32	25	18	11	4	41	
34	27	20	13	6	43	36	29	22	15	⑧	

The slots lying in the same column are in-phase slots. Slots 30 and 8 have one coil side (one conductor) omitted. The broken lines show the division of the slots among the 3 phases. Each phase consists of $4 = (\frac{p}{d}) \times a$ waves. Two parallel circuits are possible. The distribution chosen in this example is such that the 2 omitted coils (conductors) are the last coils (conductors) of 2 waves and that 2 parallel paths are possible. This makes the errors large (see Art. 5-5). The error in magnitude is zero; the errors in the angles are -3° 54' for phase C and -5° 27' for phase B. Maintaining the 2 parallel circuits and omitting conductors in slots 4 and 26, or 11 and 33 (instead of slots 8 and 30) which are not the last of the waves, the errors in the angles become -3° 54' for phase C and -3° 7' for phase B and the error in the magnitude is 1.3%. The arrangement of 2 parallel circuits should be avoided in this case. This arrangement makes it necessary to omit in-phase conductors, i.e., 2 conductors lying in the same column. If, for series connection, the distribution is

1	38	31	㉔	17	10	3	40	33	26	19	
12	5	42	35	28	21	14	7	44	37	30	
23	16	9	2	39	32	25	⑱	11	4	41	y-series
34	27	20	13	6	43	36	29	22	15	8	

and coils are left out in slots 24 and 18, the errors in the angles are +46' for phase C and $+1^{\circ}$ 32' for phase B. The error in magnitude is 0.15%.

More examples of unbalanced, fractional-slot wave windings with $\frac{S}{m} \neq$ integer are given in Art. 8-8.

A4-6. Determination of the Magnitude of Unbalance. The method for determining the amount of unbalance explained below applies to lap as well as to wave windings. In both cases, the D-series of the windings are to be used and the assignment of the slots to the m phases can be indicated by broken lines.

The D-series of only d poles are to be considered for lap windings with $\frac{S}{m}$ = integer, while all D-series of the winding are to be considered for the lap windings with $\frac{S}{m} \neq$ integer and for all wave windings.

The method for determining the amount of unbalance will be explained by several examples.

(a) $\frac{S}{m}$ = an integer.

Consider a 3-phase, 6-pole lap winding with $q = 2\frac{2}{3}$. For this winding, N = 8, d = 3, and S = 48. Since S is divisible by m, the m = 3 D-series of only d = 3 poles are to be considered. According to Eqs. A4-3 and A4-1,

$$D = \frac{3 \times 8 \times P + 3}{3} = 1 \text{ with } (P = 0) \qquad \alpha_m = \frac{180^\circ}{8} = 22\tfrac{1}{2}^\circ$$

The 3 D-series with N = 8 slots in each are

	A			C		B		
1	2	3	4	5	6	7	8	
9	10	11	12	13	14	15	16	D-series for d = 3 poles
17	18	19	20	21	22	23	24	

The broken lines divide the 3 phases from each other. The slots lying in the same column are in-phase slots and, therefore, can be considered as a slot unit.

If a centerline is drawn through phase C, between the slot units (4, 12, 20) and (5, 13, 21), it will be observed that phases A and B have symmetrical positions with respect to this centerline. Therefore, it suffices to calculate the angle between phases A and C and the magnitudes of phases A and C only.

A simplification in the calculations is achieved when groups of slot-units are considered instead of each slot-unit separately. Thus in the example considered, the units (1, 9, 17) and (2, 10, 18) of phase A can be treated as a group and also the units (4, 12, 20) and (5, 13, 21) of phase C can be treated as a group.

If N' is the number of slot-units in the group, the distribution factor of the group is (see Art. A5-2)

$$k_d = \frac{\sin N' \ (\alpha_m/2)}{N' \sin \ (\alpha_m/2)} \tag{A4-11}$$

and for the winding of the example

$$k_d = \frac{\sin 2 \ (22.5/2)}{2 \sin \ (22.5/2)} = 0.981$$

Considering the D-series, phase A consists of 2 groups, one of which is comprised of the slots 1, 9, 17, 2, 10, 18, and the other of the slots 3 and 19. Phase C consists of 3 groups, one of which is slot 11, the second of which is comprised of the slots 4, 12, 20, 5, 13, 21, and the third is slot 6. With slot 1 as reference, the group angles are

	A			C	
1	2	3	4	5	6
9	10	11	12	13	14
17	18	19	20	21	22
0°	11.25°	45°	78.75°		112.5°

Assuming that the magnitude of the voltage or mmf of one slot is equal to 1, that of the 6 slots making the larger groups of phases A and C is 6 x 0.981 = 5.886. Thus the cosine and sine components for phase A are

$$\begin{array}{lrlr} 5.886 \times \cos 11.25^\circ = & 5.771 & \qquad 5.886 \times \sin 11.25^\circ = & 1.148 \\ 2.0 \times \cos 45^\circ = & \underline{1.414} & \qquad 2.0 \times \sin 45^\circ = & \underline{1.414} \\ & 7.185 & & 2.562 \end{array}$$

and for phase C

$$\begin{array}{lrlr} 1.0 \times \cos 45^\circ = & 0.707 & \qquad 1.0 \times \sin 45^\circ = & 0.707 \\ 5.886 \times \cos 78.75^\circ = & 1.148 & \qquad 5.886 \times \sin 78.75^\circ = & 5.771 \\ 1.0 \times \cos 112.5^\circ = & \underline{-0.383} & \qquad 1.0 \times \sin 112.5^\circ = & \underline{0.924} \\ & 1.472 & & 7.402 \end{array}$$

The magnitudes of phase A and B are

$$E_A = E_B = \sqrt{(7.185)^2 + (2.562)^2} = 7.628$$

and the magnitude of phase C is

$$E_C = \sqrt{(1.472)^2 + (7.402)^2} = 7.547$$

The average voltage is

$$E_{avg} = \frac{2 \times 7.628 + 7.547}{3} = 7.601$$

and the distribution factor of the winding for the main wave

$$k_d = \frac{7.601}{8} = 0.950$$

For phases A and C

$$\tan \varphi_A = \frac{2.562}{7.185} = 0.356 \qquad \varphi_A = 19^\circ\ 37'$$

$$\tan \varphi_C = \frac{7.402}{1.472} = 5.027 \qquad \varphi_C = 78^\circ\ 45'$$

The angle between phase A and phase C is

$$\varphi_C - \varphi_A + 180 = 78^\circ\ 45' - 19^\circ\ 37' + 180^\circ = 239^\circ\ 8' \text{ (Error } 52')$$

and the angle between phase B and A is

$$\varphi_B - \varphi_A = 2(78^\circ\ 45' - 19^\circ\ 37') = 118^\circ\ 16' \text{ (Error } 1^\circ\ 44')$$

Since $\alpha_m = \frac{180^\circ}{N}$, the unbalance of the windings with S/m = an integer, laid out for maximum distribution factor of the main wave, depends upon the magnitude of N. The magnitude of unbalance is the same for different values of q with the same value of N. Thus it is the same for $q = 1\frac{4}{9}$ and for $q = 4\frac{1}{3}$.

The 3-phase, 6-pole lap winding with $q = 2\frac{2}{3}$ treated in the example will now be laid out as wave winding and its unbalance determined. All $(\frac{p}{d}) \times m = (\frac{6}{3}) \times 3 = 6$ D-series are to be considered for the wave winding. These series are

	A			C			B
1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48

D-series of all 6 poles

The distribution of the slots among the 3 phases is indicated by broken lines. Comparing this slot distribution with that given above for the lap winding, it is seen that the position of the centerline of phase C and the positions of phases A and B with respect to this centerline are the same as for the lap winding. Therefore, the unbalance also will be the same.

(b) $\frac{S}{m} \neq$ an integer.

Consider the 3-phase, 8-pole winding with 52 slots treated as a wave winding in Art. A4-5. For this winding, $q = 2\frac{1}{6}$, $N = 13$, $d = 6$, and $D = 7$. The $\frac{S}{N} = 4$ D-series are

	A				C				B			A
1	8	2	9	3	10	4	11	5	12	6	13	7
14	21	15	22	16	23	17	24	18	25	19	26	20
27	34	28	35	29	36	30	37	31	38	32	39	33
40	47	41	48	42	49	43	50	44	51	45	(52)	46

The division lines are those which have been taken for the layout as a wave winding. The same slot division can be used for the layout as a lap winding.

There is no symmetry of phases A and B with respect to phase C when $\frac{S}{m} \neq$ integer, and the magnitudes and angles of all 3 phases are to be calculated.

Using the vertical row with slot 1 as the zero reference, the above D-series can be rewritten as follows:

		A				C				B		
7	1	8	2	9	3	10	4	11	5	12	6	13
20	14	21	15	22	16	23	17	24	18	25	19	26
33	27	34	28	35	29	36	30	37	31	38	32	39
46	40	47	41	48	42	49	43	50	44	51	45	(52)

$0^\circ \rightarrow$

$6\frac{12}{13}^\circ \rightarrow$ $41\frac{7}{13}^\circ \rightarrow$ $69\frac{3}{13}^\circ \rightarrow$ $96\frac{12}{13}^\circ \rightarrow$ $124\frac{8}{13}^\circ \rightarrow$ $152\frac{4}{13}^\circ \rightarrow$

The angle α_m for this winding is

$$\alpha_m = \frac{180}{13} = 13\frac{11}{13}^{\circ}$$

The 4 slot-units of phase A (7, 20, 33, 46), (1, 14, 27, 40), (8, 21, 34, 47), and (2, 15, 28, 41) can be treated as a group. The 3 slot-units of phase C (3, 16, 29, 42), (10, 23, 36, 49), and (4, 17, 30, 43) can be used as a group; and similarly the 3 slot-units of phase B (5, 18, 31, 44), (12, 25, 38, 51), and (6, 19, 32, 45). With N' = 4, the distribution factor of the group is (Eq. A4-11):

$$k_d = \frac{\sin 4 \times (13\frac{11}{13}/2)}{4 \sin (13\frac{11}{13}/2)} = 0.964$$

With N' = 3, the distribution factor of the group is

$$k_d = \frac{\sin 3 \times (13\frac{11}{13}/2)}{3 \sin (13\frac{11}{13}/2)} = 0.981$$

Assuming that the magnitude of the emf or mmf of one slot is equal to 1, the magnitude of the group considered in phase A is equal to $16 \times k_d = 16 \times 0.964 = 15.424$. In a similar manner, the magnitude of the groups considered in phases C and B are $12 \times 0.981 = 11.772$. Phase A consists of 2 parts, phase C and phase B, each of 3 parts. Their relative magnitudes and angles with respect to slot 1 are:

$$\overbrace{\begin{array}{cc} 15.424 & 1 \\ 6\frac{12}{13}^{\circ} \rightarrow\vert & 41\frac{7}{13}^{\circ} \rightarrow\vert \end{array}}^{A} \quad \overbrace{\begin{array}{ccc} 3 & 11.772 & 2 \\ 41\frac{7}{13}^{\circ} \rightarrow\vert & 69\frac{3}{13}^{\circ} \rightarrow\vert & 96\frac{12}{13}^{\circ} \rightarrow\vert \end{array}}^{C} \quad \overbrace{\begin{array}{ccc} 2 & 11.772 & 3 \\ 96\frac{12}{13}^{\circ} \rightarrow\vert & 124\frac{8}{13}^{\circ} \rightarrow\vert & 152\frac{4}{13}^{\circ} \rightarrow\vert \end{array}}^{B}$$

The cosine and sine components of the 3 phases are:

For phase A:

$$\begin{array}{lll} 15.424 \times \cos 6\frac{12}{13}^{\circ} & = & 15.311 \\ 1 \times \cos 41\frac{7}{13}^{\circ} & = & \underline{0.748} \\ & & 16.059 \end{array} \qquad \begin{array}{lll} 15.424 \times \sin 6\frac{12}{13}^{\circ} & = & 1.859 \\ 1 \times \sin 41\frac{7}{13}^{\circ} & = & \underline{0.663} \\ & & 2.522 \end{array}$$

For phase C:

$$\begin{array}{lll} 3 \times \cos 41\frac{7}{13}^{\circ} & = & 2.246 \\ 11.772 \times \cos 69\frac{3}{13}^{\circ} & = & 4.174 \\ 2 \times \cos 96\frac{12}{13}^{\circ} & = & \underline{-0.241} \\ & & 6.179 \end{array} \qquad \begin{array}{lll} 3 \times \sin 41\frac{7}{13}^{\circ} & = & 1.989 \\ 11.772 \times \sin 69\frac{3}{13}^{\circ} & = & 11.005 \\ 2 \times \sin 96\frac{12}{13}^{\circ} & = & \underline{1.985} \\ & & 14.979 \end{array}$$

For phase B:

$$\begin{array}{rlr@{\qquad}rlr}
2 & \times \cos 96\frac{12}{13}^{\circ} & = -0.241 & 2 & \times \sin 96\frac{12}{13}^{\circ} & = 1.985 \\
11.772 & \times \cos 124\frac{8}{13}^{\circ} & = -6.686 & 11.772 & \times \sin 124\frac{8}{13}^{\circ} & = 9.686 \\
3 & \times \cos 152\frac{4}{13}^{\circ} & = \underline{-2.656} & 3 & \times \sin 152\frac{4}{13}^{\circ} & = \underline{1.394} \\
 & & -9.583 & & & 13.065
\end{array}$$

The magnitudes and angles of the 3 phases are

$$E_A = \sqrt{(16.059)^2 + (2.522)^2} = 16.25 \qquad \tan \varphi_A = \frac{2.522}{16.059} = 0.157 \qquad \varphi_A = 8^{\circ}\ 56'$$

$$E_C = \sqrt{(6.179)^2 + (14.979)^2} = 16.20 \qquad \tan \varphi_C = \frac{14.979}{6.179} = 2.424 \qquad \varphi_C = 67^{\circ}\ 35'$$

$$E_B = \sqrt{(9.583)^2 + (13.065)^2} = 16.20 \qquad \tan \varphi_B = -\frac{13.065}{9.583} = -1.363 \qquad \varphi_B = 126^{\circ}\ 15'$$

The average voltage is

$$E_{avg} = \frac{16.25 + 16.20 + 16.20}{3} = 16.22$$

and the distribution factor of the winding for the main wave is

$$k_d = \frac{16.22}{17} = 0.954$$

The angle between phase C and phase A is

$\varphi_C - \varphi_A + 180 = 67^{\circ}\ 35' - 8^{\circ}\ 55' + 180^{\circ} = 238^{\circ}\ 40'$ (Error = 1° 20')

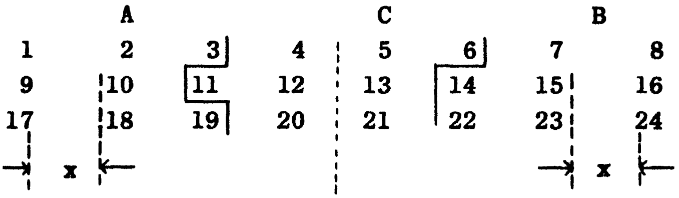
and the angle between phase B and phase A is

$\varphi_B - \varphi_A = 126^{\circ}\ 15' - 8^{\circ}\ 55' = 117^{\circ}\ 20'$ (Error = 2° 40')

(c) Simple method for checking the errors in the angles.

The error in magnitude in windings with N/m = integer is small when N > 8 (see Table 5-7). The same is true of the windings with N/m ≠ integer, if t = 2 and N = 11 (see Tables 5-5 and 5-6). In these cases, it suffices to determine the error in the angle only. This can be done approximately by weighing the in-phase groups (the columns) of coils. The method will be explained by the 2 examples treated previously in this Article.

$\frac{S}{m}$ = an integer. 3 phases, 6-poles, q = 2 2/3. The m = 3 D-series in d = 3 poles are



	A			C		B	
1	2	3	4	5	6	7	8
9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24

Phase A consists of the in-phase groups (1, 9, 17), (2, 10, 18) and (3, 19). The center of gravity of this phase will lie between the first and second column, close to the second column. If the angle between the first column, as reference, and the center of gravity line is designated by x, then

$$3x = 3\ (\alpha_m - x) + 2\ (\alpha_m + \alpha_m - x)$$

or $x = \frac{7}{8}\alpha_m$. Since $\alpha_m = \frac{180^\circ}{N} = \frac{180^\circ}{8} = 22.5^\circ$, $x = 19.69^\circ = \varphi_A$*.

The center of gravity of phase C lies in the middle between the in-phase groups (4, 12, 20) and (5, 13, 21). Phase B consists of groups which have the same weight as those of phase A and, therefore, its center of gravity is shifted x degrees from the last column.

The angle between the center of gravity of phase C and the reference column is

$$\varphi_C = 3.5 \times \alpha_m + 180 = 258.75^\circ$$

and the angle between the center of gravity of phase B and the reference column is

$$\varphi_B = 7 \times \alpha_m - x = 157.5^\circ - 19.69^\circ = 137.81^\circ$$

Thus, the angle between phase A and phase C is

$$\varphi_C - \varphi_A = 258.75^\circ - 19.69^\circ = 239.06^\circ = 239^\circ\ 3.6' \quad (\text{Error} = 56')$$

and the angle between phase B and phase A is

$$\varphi_B - \varphi_A = 137.81^\circ - 19.69^\circ = 118.12^\circ = 118^\circ\ 8' \quad (\text{Error} = 1^\circ\ 52')$$

$\underline{\frac{S}{m} \neq \text{an integer.}}$ 3-phases, 8-poles, $q = 2\frac{1}{6}$. The t = 4 D-series, representing the total winding, are (rearranged)

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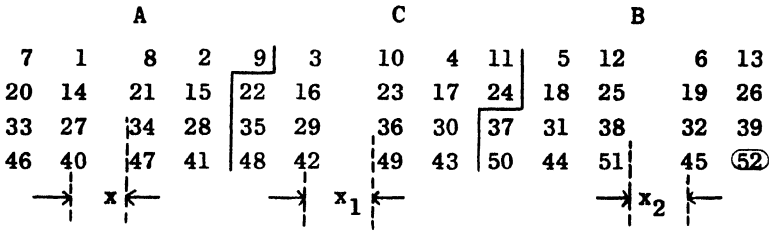
* This result is slightly different from that obtained on page 713 by the cosine-sine method, but it is within slide-rule accuracy.



		A				C				B		
7	1	8	2	9	3	10	4	11	5	12	6	13
20	14	21	15	22	16	23	17	24	18	25	19	26
33	27	34	28	35	29	36	30	37	31	38	32	39
46	40	47	41	48	42	49	43	50	44	51	45	(52)

Using the second column of phase A as reference for this phase

$$4\ (\alpha_m + x) + 4x = 4\ (\alpha_m - x) + 4\ (2\alpha_m - x) + (3\alpha_m - x)$$

$$\alpha_m = 13\tfrac{11}{13}^{\circ} \qquad x = \frac{11}{17}\,\alpha_m = 8^{\circ}\ 57.6'$$

Using for phase C the second column of this phase as reference

$$3\ (\alpha_m + x_1) + 4\ x_1 = 4\ (\alpha_m - x_1) + 4\ (2\alpha_m - x_1) + 2\ (3\alpha_m - x_1)$$

$$x_1 = \frac{15}{17}\,\alpha_m = 12^{\circ}\ 13'$$

Using for phase B the column (6, 19, 32, 45) as reference

$$x_2 = x_1 = 12^{\circ}\ 13'$$

Referring all 3 phases to the first column of phase A (7, 20, 33, 46) as reference

$$\varphi_A = \alpha_m + x = 13^{\circ}\ 50.7' + 8^{\circ}\ 57.6' = 22^{\circ}\ 48.3'$$

$$\varphi_C = 5 \times 13^{\circ}\ 50.7' + 12^{\circ}\ 13' + 180^{\circ} = 261^{\circ}\ 25'$$

$$\varphi_B = 11 \times 13^{\circ}\ 50.7' - 12^{\circ}\ 13' = 140^{\circ}\ 5.3'$$

$$\varphi_C - \varphi_A = 261^{\circ}\ 25' - 22^{\circ}\ 48' = 238^{\circ}\ 37' \qquad \text{(Error } 1^{\circ}\ 23'\text{)}$$

$$\varphi_B - \varphi_A = 140^{\circ}\ 5' - 22^{\circ}\ 48' = 117^{\circ}\ 17' \qquad \text{(Error } 2^{\circ}\ 43'\text{)}$$

These are the same values as those found by the cosine-sine method.

APPENDIX 5

DISTRIBUTION AND PITCH FACTORS OF INTEGRAL AND FRACTIONAL-SLOT WINDINGS

A5-1. Integral-slot Windings. The synchronous (main) wave, the length of which is equal to 2t (= twice the pole pitch), is used as the fundamental wave for integral-slot windings. The order of the harmonics is designated by n. n = 1 is the synchronous (main) wave.

In 2-phase windings, the slots lying under one pole pitch (= 180 electrical degrees) are divided into 2 parts, one for each phase. The 2-phase windings, therefore, are 2-zone (90° phase-belt) windings. The 3-phase windings can be made 6-zone or 3-zone. In the 6-zone windings, the slots lying under one pole pitch (= 180 electrical degrees) are divided into 3 parts, one for each phase, yielding 6 zones in 2 poles. In the 3-zone windings the slots lying under 2 poles are divided into 3 parts, yielding a 3 zone winding. When the winding is an integral-slot winding, each zone of the 6-zone winding comprises 60 electrical degrees. Normally, the 6-zone winding is used. The 3-zone winding is used in special cases as, for example, in 2-speed motors (see Art. 9-1).

(a) Three-phase 60° phase-belt (6-zone) stator windings. Distribution factors. The harmonics produced by such a stator winding are

$$n = 1,\ 5,\ 7,\ 11,\ 13,\ 17\ldots$$

Harmonics which are a multiple of 3 do not appear unless zero-sequence currents flow in the winding. They can be considered as non-existent in induction motors.

For the synchronous (main) wave,

$$k_{d(n = 1)} = \frac{0.5}{q \sin \frac{30^\circ}{q}} \qquad \text{(A5-1)}$$

where $q = \frac{S}{mp}$ is the number of slots per pole per phase. The values of $k_{d(n = 1)}$ are given in Fig. A5-1.

For the nth harmonic

$$k_{dn} = \frac{\sin n \times 30^\circ}{q \sin n \frac{30^\circ}{q}} \qquad \text{(A5-2)}$$

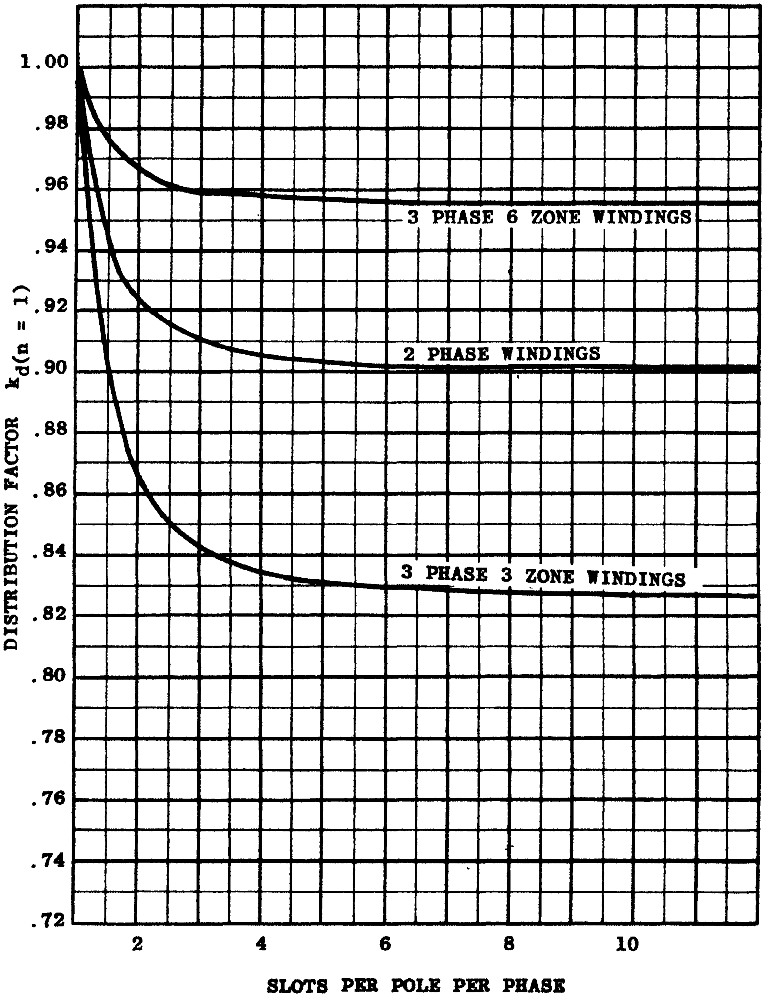


Fig. A5-1. Distribution factors of the main wave of 2-phase and 3-phase windings.

The values of k_{dn} corresponding to Eq. A5-2, for the synchronous wave and the harmonics, are given in Table A5-1. Eq. A5-2 yields the correct signs of the harmonics. For the absolute values only

$$k_{dn} = \frac{0.5}{q \sin n \frac{30^\circ}{q}} \qquad \text{(A5-2a)}$$

Pitch factors. For the synchronous (main) wave,

$$k_{p(n = 1)} = \sin \frac{W}{t} \frac{\pi}{2} \qquad \text{(A5-3)}$$

where t is the pole pitch, and W the coil width in units of t. The values of $k_{p(n = 1)}$ are given in Fig. A5-2.

For the nth harmonic,

$$k_{pn} = \sin n \frac{W}{t} \frac{\pi}{2} \qquad \text{(A5-3a)}$$

The values of k_{pn} corresponding to this equation for the synchronous wave and the harmonics are given in Table A5-2.

(b) Three-phase 60° phase-belt (6-zone) rotor windings. The harmonics produced by such a rotor winding are

$$m = 3k_2 + n \qquad \text{(A5-4)}$$

where k_2 is any positive or negative even integer including 0. n is to be introduced with the right sign (the signs of the stator harmonics n alternate; the plus sign is normally assigned to the main wave so that n = +1, -5, +7, -11, ...). In the induction motor, Eq. A5-4 yields, for n = 1, the rotor harmonics produced by the currents of slip frequency.

The distribution and pitch factors are given by Eqs. A5-1 to A5-3a and Figs. A5-1 and A5-2. m is to be introduced for n in all equations.

(c) Three-phase 120° phase-belt (3-zone) stator windings. Distribution factors. The harmonics produced by such a stator winding are

$$n = 1, 2, 4, 5, 7, 8, 10...$$

n = 1 is the synchronous (main) wave. The even harmonics occur only in chorded (fractional-pitch) windings.

For the synchronous wave,

$$k_{d(n = 1)} = \frac{0.866}{2q \sin \frac{30^\circ}{q}} \qquad \text{(A5-5)}$$

where q again is the number of slots per pole phase, i.e., $q = \frac{S}{mp}$.

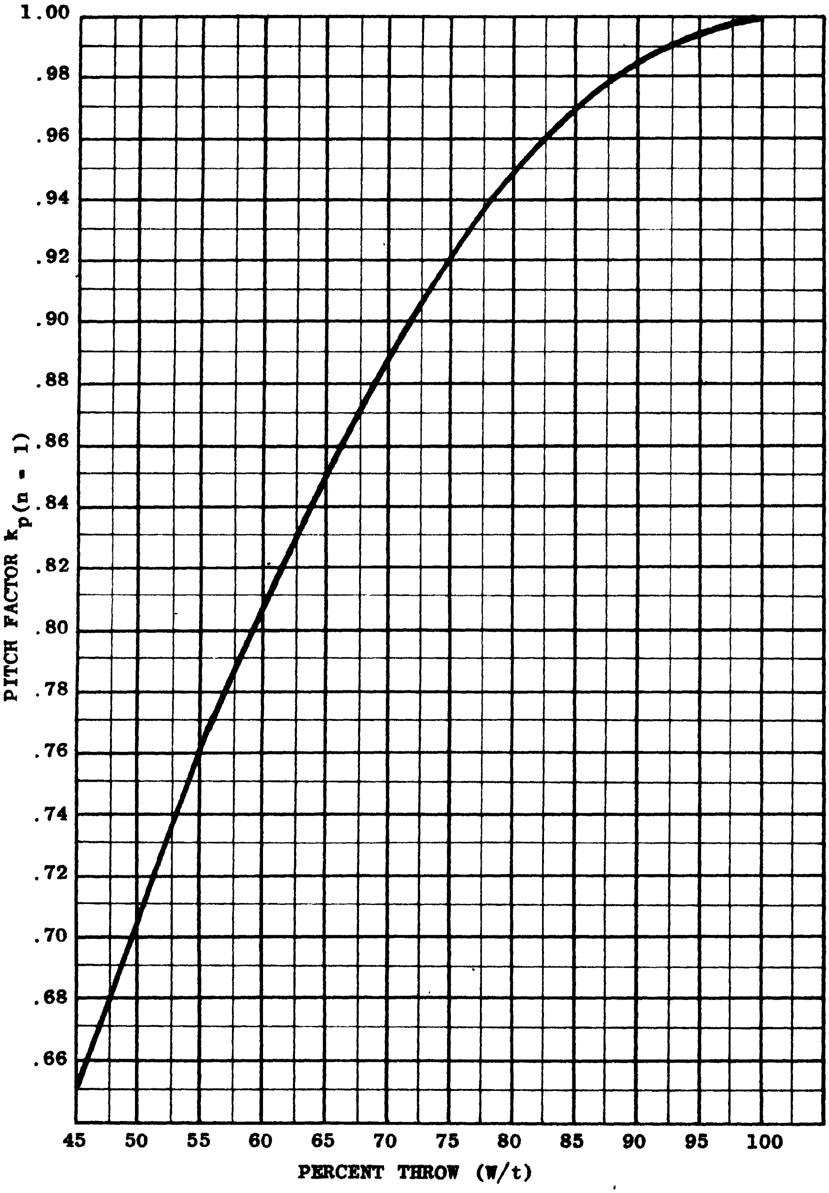


Fig. A5-2. Pitch factors of the main wave.

The values of $k_{d(n = 1)}$ are given in Fig. A5-1.

For the nth harmonic,

$$k_{dn} = \frac{\sin n \times 60^\circ}{2q \sin n \frac{30^\circ}{q}} \qquad \text{(A5-6)}$$

Eq. A5-6 yields the correct signs. For the absolute values only

$$k_{dn} = \frac{0.866}{2q \sin n \frac{30^\circ}{q}} \qquad \text{(A5-6a)}$$

Pitch factors. The same formulae and Fig. A5-2 which apply to the 3-phase 60° phase-belt windings apply here also.

(d) Two-phase stator windings. Distribution factors. The harmonics produced by such a stator winding are

$$n = 1, 3, 5, 7, 9, 11, 13\ldots$$

$n = 1$ is the synchronous (main) wave. For this wave

$$k_{d(n = 1)} = \frac{0.707}{q \sin \frac{45^\circ}{q}} \qquad \text{(A5-7)}$$

The values of $k_{d(n = 1)}$ are given in Fig. A5-1.

For the nth harmonic,

$$k_{dn} = \frac{\sin n \times 45^\circ}{q \sin n \frac{45^\circ}{q}} \qquad \text{(A5-8)}$$

Pitch factors. The same formulae and Fig. A5-2 which apply to the 3-phase 60° phase-belt windings apply here also.

(e) Single-phase windings. Refer to Fig. A5-3 which shows a concentric winding with different numbers of turns in the coils. For this winding, the product of distribution factor and pitch factor of the main wave is

$$k_d \times k_p = \frac{N_{C1}, \sin \alpha_1, + N_{C2} \sin \alpha_2 + N_{C3} \sin \alpha_3 + \ldots}{N_{C1} + N_{C2} + N_{C3}} \qquad \text{(A5-9)}$$

When the single-phase winding is not a concentric but a 2-layer winding of the same kind as the 3-phase and 2-phase windings considered under (a) to (c), the distribution factor of the main wave is

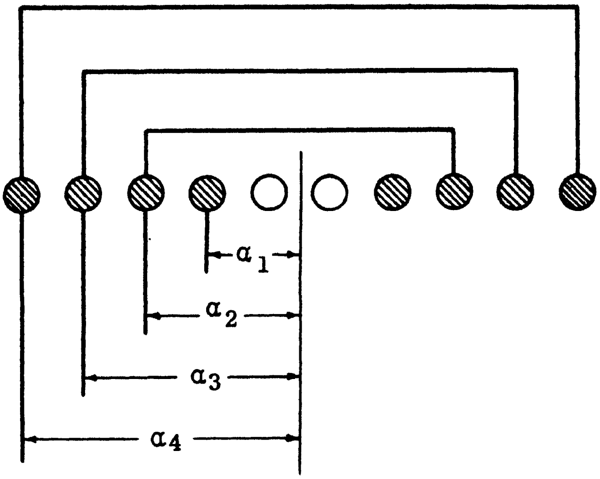


Fig. A5-3. Derivation of the winding factor of a concentric single-phase winding.

$$k_d = \frac{\sin \frac{q}{S_p} 90^\circ}{q \sin \frac{90^\circ}{S_p}} \tag{A5-10}$$

where S_p is the number of slots per pole, and q the number of slots per pole containing conductors. The pitch factor is the same as for the 3-phase and 2-phase windings and Fig. A5-2 can be used.

A5-2. Balanced, Fractional-slot Windings Laid Out for Maximum Distribution Factor of the Synchronous (Main) Wave. A 2-pole wave, the length of which is equal to 2pt (= circumference of the armature), is used as the fundamental wave for fractional-slot windings. The order of the harmonics is designated by n'. $n' = \frac{p}{2}$ is the synchronous (main) wave.

Three-phase windings can be 6-zone windings (corresponding to the 60° phase-belt windings) or 3-zone windings (corresponding to the 120° phase-belt windings.)

(a) Three-phase, 6-zone stator windings. Distribution factors. The number of slots per pole per phase is

$$q = \frac{N}{d} \tag{A5-11}$$

where N and d have no common divisor.

The following harmonics are produced by a stator winding,

d = even number:

$$n' = \frac{p}{d}\nu \qquad \nu = 1, 2, 4, 5, 7, 8... \qquad \text{(A5-12a)}$$

For the synchronous (main) wave, $n' = \frac{p}{2}$ and $\nu_s = \frac{d}{2}$

d = odd number:

$$n' = \frac{p}{2d}\nu \qquad \nu = 1, 5, 7, 11, 13... \qquad \text{(A5-12b)}$$

For the synchronous (main) wave, $n' = \frac{p}{2}$ and $\nu_s = d$.

(See note under (a) of A5-1 about the harmonics which are multiples of 3.)

For the synchronous wave,

$$k_{p(n' = \frac{p}{2})} = \frac{0.5}{N \sin \frac{30^\circ}{N}} \qquad \text{(A5-13)}$$

It can be seen by comparing Eq. A5-13 with Eq. A5-1 that the distribution factor of the main wave of a fractional-slot winding is equal to that of a integral-slot winding with N slots per pole per phase. Therefore, Fig. A5-1 can be used here also but for q = N.

The distribution factor of the n'th harmonic is

$$k_{dn'} = \frac{\sin N\ (\alpha_{n'}/2)}{N \sin\ (\alpha_{n'}/2)} \qquad \text{(A5-14)}$$

In order to find $\alpha_{n'}$, determine

$$D = \frac{3NP + 1}{d} \qquad \text{(A5-15)}$$

where P is the smallest integer which makes D and integer. Then

$$\alpha_{n'} = n' D\, \alpha_m \frac{2d}{p} \qquad \text{when P is even}$$

$$\alpha_{n'} = n' D\, \alpha_m \frac{2d}{p} + 180^\circ, \text{ when P is odd and d is even} \qquad \text{(A5-16)}$$

$$\alpha_{n'} = n'\ (D\, \alpha_m + 180^\circ)\ \frac{2d}{p}, \text{when P is odd and d is odd}$$

$$\alpha_m = \frac{180^\circ}{3N} \qquad \text{(A5-17)}$$

Eq. A5-14 in connection with Eq. A5-16 yields the correct sign of the harmonics. For the absolute value only

$$k_{dn'} = \frac{0.5}{N \cos\ (\frac{D}{N}\ 60^\circ \times \nu)}, \text{when d is even}$$

$$k_{dn'} = \frac{0.5}{N \sin\ (\frac{D}{N}\ 30^\circ \times \nu)}, \text{when d is odd and P is even} \qquad \text{(A5-18)}$$

$$k_{dn'} = \frac{0.5}{N \cos\ (\frac{D}{N}\ 30^\circ \times \nu)}, \text{when d is odd and P is odd}$$

Pitch factors. For the synchronous wave,

$$k_{p(n' = \frac{p}{2})} = \sin \frac{W}{t} \frac{\pi}{2} \qquad \text{(A5-19)}$$

This is the same as for integral-slot windings and Fig. A5-2 can be used.

For the n'th harmonic,

$$k_{pn'} = \sin \frac{W}{t} \frac{180^\circ}{d} \nu \text{, when d is even}$$

$$k_{pn'} = \sin \frac{W}{t} \frac{180^\circ}{2d} \nu \text{, when d is odd.}$$

(b) Three-phase 6-zone rotor windings. The harmonics produced by such a rotor winding are

$$m' = 3\frac{p}{d} k_2 + n' \qquad \text{(A5-21)}$$

where k_2 is any positive or negative integer including 0. n' is to be introduced with the right sign. In the induction motor, $n' = \frac{p}{2}$ yields the rotor harmonics produced by currents of slip frequency.

The distribution factors are given by Eqs. A5-13 to A5-18 and Fig. A5-1. m' is to be introduced for n' in all equations.

The pitch factor of the main wave $m' = \frac{p}{2}$ is given by Eq. A5-19 and Fig. A5-2. The pitch factor of the m'th harmonic is

$$k_{pm'} = \sin Zd\ (\alpha_{m'}/2) \qquad \text{(A5-21a)}$$

where Z is the coil width in slot pitches and $\alpha_{m'}$ is given by Eq. A5-16.

(c) Two-phase stator windings. Distribution factors. The number of slots per pole per phase is

$$q = \frac{N}{d}$$

where N and d have no common divisor. Here only odd values of d are possible. Even values of d yield unbalanced windings.

The following harmonics are produced by a stator winding.

$$n' = \frac{p}{2d}\nu \qquad \nu = 1, 3, 5, 7, 9\ldots$$

For the synchronous wave, $n' = \frac{p}{2}$ and $\nu_s = d$

For the synchronous (main) wave,

$$k_{d(n' = \frac{p}{2})} = \frac{0.707}{N \sin \frac{45^\circ}{N}} \qquad \text{(A5-22)}$$

and for the n'th harmonic,

$$k_{dn'} = \frac{\sin N\,(\alpha_{n'}/2)}{N \sin\,(\alpha_{n'}/2)} \tag{A5-23}$$

$\alpha_{n'}$ is given by Eqs. A5-16 and A5-17. 2 is to be substituted for 3 in Eqs. A5-15 and A5-17.

Pitch factors. For the synchronous wave,

$$k_{p(n' = \frac{p}{2})} = \sin \frac{W}{t} \frac{\pi}{2} \tag{A5-24}$$

This is the same as for integral-slot windings, and Fig. A5-2 can be used.

For the n'th harmonic,

$$k_{pn'} = \sin \frac{W}{t} \frac{180^\circ}{2d} \nu \tag{A5-25}$$

TABLE A5-1 - VALUES OF k_{dn} FOR INTEGRAL-SLOT 3 PHASE WINDINGS

n	k_{dn} - HARMONIC DISTRIBUTION FACTORS								
q=	2	3	4	5	6	7	8	9	10	∞
1	0.966	0.960	0.958	0.957	0.957	0.957	0.956	0.955	0.955	0.955
3	0.707	0.667	0.654	0.646	0.644	0.642	0.641	0.640	0.639	0.636
5	0.259	0.217	0.205	0.200	0.197	0.195	0.194	0.194	0.193	0.191
7	-0.259	-0.177	-0.158	-0.149	-0.145	-0.143	-0.141	-0.140	-0.140	-0.136
9	-0.707	-0.333	-0.270	-0.247	-0.236	-0.229	-0.225	-0.222	-0.220	-0.212
11	-0.966	-0.177	-0.126	-0.110	-0.102	-0.097	-0.095	-0.093	-0.092	-0.087
13	-0.966	0.217	0.126	0.102	0.092	0.086	0.083	0.081	0.079	0.073
15	-0.707	0.667	0.270	0.200	0.172	0.158	0.150	0.145	0.141	0.127
17	-0.259	0.960	0.158	0.102	0.084	0.075	0.070	0.066	0.064	0.056
19	0.259	0.960	-0.205	-0.110	-0.084	-0.072	-0.066	-0.062	-0.060	-0.059
21	0.707	0.667	-0.654	-0.247	-0.172	-0.143	-0.127	-0.118	-0.112	-0.091
23	0.966	0.217	-0.958	-0.149	-0.092	-0.072	-0.063	-0.057	-0.054	-0.041
25	0.966	-0.177	-0.958	0.200	0.102	0.075	0.063	0.056	0.052	0.038
27	0.707	-0.333	-0.654	0.646	0.236	0.158	0.127	0.111	0.101	0.071
29	0.259	-0.177	-0.205	0.957	0.145	0.086	0.066	0.056	0.050	0.033
31	-0.259	0.217	0.158	0.957	-0.197	-0.097	-0.070	-0.057	-0.050	-0.031

33	−0.709	0.667	0.270	0.646	−0.644	−0.229	−0.150	−0.118	−0.101	−0.058
35	−0.966	0.960	0.126	0.200	−0.957	−0.143	−0.083	−0.062	−0.052	−0.027
37	−0.966	0.960	−0.126	−0.149	−0.957	0.195	0.095	0.066	0.054	0.026
39	−0.707	0.667	−0.270	−0.247	−0.644	0.642	0.225	0.145	0.112	0.049
41	−0.259	0.217	−0.158	−0.110	−0.197	0.957	0.141	0.081	−0.060	0.023
43	0.259	−0.177	0.205	0.102	0.145	0.957	−0.194	−0.093	−0.064	−0.022
45	0.707	−0.333	0.654	0.200	0.236	0.642	−0.641	−0.222	−0.141	−0.042
47	0.966	−0.177	0.958	0.102	0.102	0.195	−0.956	−0.140	−0.079	−0.020
49	0.966	0.217	0.958	−0.110	−0.092	−0.143	−0.956	0.194	0.092	0.019
51	0.707	0.667	0.654	−0.247	−0.172	−0.229	−0.641	0.640	0.220	0.038
53	0.259	0.960	0.205	−0.149	−0.084	−0.097	−0.194	0.955	0.140	0.018
55	−0.259	0.960	−0.158	0.200	0.084	0.086	0.141	0.955	−0.193	−0.017
57	−0.707	0.667	−0.270	0.646	0.172	0.158	0.225	0.640	−0.639	−0.033
59	−0.966	0.217	−0.126	0.957	0.092	0.075	0.095	0.194	−0.955	−0.016
61	−0.966	−0.177	0.126	0.957	−0.102	−0.072	−0.083	−0.140	−0.955	0.016
63	−0.707	−0.333	0.270	0.646	−0.236	−0.143	−0.150	−0.222	−0.639	0.030
65	−0.259	−0.177	0.158	0.200	−0.145	−0.072	−0.070	−0.093	−0.193	0.015

TABLE A5-2 - VALUES OF PITCH FACTORS (k_{pn}) FOR HARMONICS AT DIFFERENT PITCHES

	PITCH FACTORS (k_{pn}) FOR HARMONICS AT DIFFERENT PITCHES																																							
	q	W/t																																						
	1	3/3																															2/3						
	2	6/6																5/6															4/6						
	3	9/9											8/9										7/9										6/9						
	4	12/12								11/12								10/12								9/12							8/12						7/12
	5	15/15						14/15							13/15						12/15							11/15						10/15				9/15		
	6	18/18					17/18						16/18					15/18					14/18						13/18					12/18						
	7	21/21				20/21					19/21					18/21				17/21					16/21					15/21				14/21						
	8	24/24			23/24					22/24				21/24				20/24				19/24				18/24					17/24			16/24			15/24			14/24
	9	27/27		26/27					25/27				24/27				23/27		22/27				21/27				20/27					19/27		18/27		17/27			16/27	
	10	30/30	29/30					28/30				27/30			26/30			25/30			24/30			23/30				22/30					21/30	20/30	19/30			18/30		
	W/t	1.0	.967	.964	.959	.952	.945	.934	.926	.917	.905	.900	.889	.875	.867	.857	.852	.833	.815	.810	.800	.792	.779	.767	.762	.750	.741	.734	.722	.712	.709	.705	.700	.667	.634	.630	.625	.600	.592	.584
ORDER OF HARMONIC	1	1.0	.999	.998	.998	.997	.996	.995	.993	.991	.989	.988	.985	.981	.978	.975	.973	.966	.958	.956	.951	.947	.940	.934	.931	.924	.918	.914	.906	.901	.897	.894	.891	.866	.839	.835	.831	.809	.800	.793
	3	-1.0	-.988	-.985	-.981	-.975	-.966	-.951	-.940	-.924	-.901	-.891	-.866	-.831	-.809	-.782	-.766	-.707	-.643	-.623	-.588	-.556	-.500	-.454	-.434	-.383	-.342	-.309	-.259	-.222	-.195	-.174	-.156	0.0	.156	.174	.195	.309	.342	.383
	5	1.0	.966	.958	.947	.931	.906	.866	.835	.793	.733	.707	.643	.556	.500	.434	.396	.259	.116	.075	0.0	-.065	-.174	-.259	-.295	-.383	-.447	-.500	-.574	-.623	-.660	-.690	-.707	-.866	-.966	-.974	-.982	-1.0	-.998	-.993
	7	-1.0	-.943	-.918	-.897	-.866	-.819	-.743	-.686	-.609	-.500	-.454	-.342	-.177	-.105	0.0	.058	.259	.449	.500	.588	.659	.766	.839	.866	.924	.958	.978	.966	1.0	.998	.993	.988	.866	.629	.588	.559	.309	.225	.139
	9	1.0	.897	.866	.831	.782	.707	.588	.500	.383	.223	.156	.00	-.191	-.304	-.434	-.500	-.707	-.866	-.901	-.951	-.981	-1.0	-.988	-.975	-.924	-.866	-.804	-.707	-.623	-.556	-.500	-.454	0.0	.358	.407	.462	.500	.755	.875
	11	-1.0	-.834	-.802	-.750	-.680	-.574	-.407	-.287	-.131	.075	.156	.342	.556	.660	.782	.795	.966	.998	.989	.951	.897	.766	.629	.583	.383	.231	.105	-.087	-.222	-.321	-.396	-.454	-.866	-.999	-.994	-.981	-.809	-.721	-.618
	13	1.0	.777	.727	.659	.563	.423	.208	.058	-.131	-.365	-.454	-.643	-.831	-.914	-.975	-.993	-.966	-.802	-.733	-.588	-.442	-.174	.052	.148	.383	.550	.669	.818	.901	.947	.973	.988	.866	.371	.294	.195	-.309	-.459	-.598
	15	-1.0	-.707	-.643	-.556	-.434	-.259	0.0	.174	.383	.624	.707	.866	.981	1.0	.975	.940	.707	.342	.223	0.0	-.195	-.500	-.707	-.782	-.924	-.981	-1.00	-.966	-.907	-.831	-.766	-.707	0.0	.696	.760	.831	1.0	.982	.930
	17	1.0	.629	.550	.442	.295	.087	-.208	-.396	-.609	-.826	-.891	-.985	-.981	-.914	-.782	-.686	-.259	.231	.365	.588	.752	.940	.999	.997	.924	.802	.669	.423	.222	.065	-.058	-.156	-.866	-.940	-.898	-.831	-.309	-.100	.113
	19	-1.0	-.545	-.449	-.321	-.149	.0872	.407	.597	.793	.956	.988	.985	.831	.669	.434	.287	-.259	-.727	-.826	-.951	-.998	-.940	-.777	-.680	-.383	-.116	.105	.423	.623	.752	.835	.891	.866	.072	-.047	-.194	-.809	-.952	-.989
	21	1.0	.454	.342	.195	0.0	-.259	-.588	-.766	-.924	-1.0	-.988	-.866	-.556	-.309	0.0	.174	.707	.985	1.0	.951	.831	.500	.156	0.0	-.383	-.643	-.804	-.966	-1.0	-.981	-.940	-.891	0.0	.881	.935	.981	.809	.628	.402
	23	-1.0	-.358	-.231	-.0644	.149	.423	.743	.894	.991	.956	.891	.643	.195	-.105	-.434	-.597	-.966	-.918	-.826	-.588	-.321	.174	.545	.680	.924	.998	.978	.819	.623	.442	.287	.156	-.866	-.792	-.696	-.555	.309	.566	.778
	25	1.0	.259	.116	.0644	-.295	-.574	-.866	-.973	-.991	-.826	-.707	-.342	.195	.500	.782	.894	.966	.550	.365	0.0	-.321	-.766	-.966	-.997	-.924	-.727	-.500	-.087	.222	.442	.597	.707	.866	-.061	-.383	-.555	-1.0	-.951	-.809
	27	-1.0	-.170	0.0	.195	.434	.707	.951	1.0	.924	.624	.454	0.0	-.556	-.809	-.975	-1.0	-.707	0.0	.223	.558	.831	1.0	.897	.782	.383	0.0	-.309	-.707	-.901	-.981	-1.0	-.988	0.0	.983	1.0	.981	.309	-.025	-.356
	29	1.0	.052	-.116	-.321	-.563	-.819	-.995	-.973	-.793	-.365	-.156	.342	.831	.978	.975	.894	.259	-.550	-.733	-.951	-.998	-.766	-.358	-.148	.383	.727	.914	.996	.901	.752	.597	.454	-.866	-.569	-.412	-.194	.809	.965	.995
	31	-1.0	.052	.231	.442	.680	.906	.995	.894	.109	.0747	-.156	-.643	-.981	-.978	-.782	-.597	.259	.918	.989	.951	.752	.174	-.358	-.583	-.924	-.998	-.914	-.574	-.222	.065	.287	.454	.866	-.517	-.673	-.831	-.809	-.525	-.162
	33	1.0	.156	-.342	-.556	-.782	-.966	-.951	-.766	-.383	.223	.454	.866	.981	.809	.434	.174	-.707	-.985	-.901	-.588	-.195	.500	.891	.975	.924	.643	.309	-.259	-.623	-.831	-.940	-.988	0.0	.992	.946	.831	-.309	-.666	-.910
	35	-1.0	.259	.449	.659	.866	.996	.866	.597	.131	-.500	-.707	-.985	-.831	-.500	0.0	.287	.966	.727	.500	0.0	-.442	-.940	-.966	-.866	-.383	.116	.500	.906	1.0	.947	.835	.707	-.866	-.294	-.079	.194	1.0	.905	.637
	37	1.0	-.358	-.550	-.750	-.931	-.996	-.743	-.396	.131	.733	.891	.985	.556	.105	-.434	-.686	-.966	-.231	.075	.588	.897	.940	.545	.295	-.383	-.802	-.978	-.906	-.623	-.321	-.058	.156	.866	-.855	-.884	-.981	-.309	.150	.577
	39	-1.0	.454	.643	.831	.975	.966	.588	.174	-.383	-.901	-.988	-.866	-.195	.309	.782	.940	.707	-.342	-.623	-.951	-.981	-.500	.156	.434	.924	.985	.809	.259	-.222	-.556	-.766	-.891	0.0	.909	.780	.555	-.809	-.990	-.939
	41	1.0	-.545	-.727	-.897	-.997	-.906	-.407	.058	.609	.989	.988	.643	-.195	-.669	-.975	-.933	-.259	.802	.956	.951	.659	-.174	-.777	-.931	-.924	-.550	-.105	.574	.901	.998	.973	.891	-.866	.010	.264	.555	.809	.414	-.088
	43	-1.0	.629	.802	.947	.997	.819	.208	-.287	-.793	-.989	-.891	-.342	.556	.914	.975	.795	-.259	-.998	-.956	-.588	-.065	.766	.999	.931	.383	-.231	-.669	-.996	-.901	-.660	-.396	-.156	.866	-.916	-.990	-.981	.309	.754	.984
	45	1.0	-.707	-.866	-.987	-.925	-.707	0.0	.500	.924	.901	.707	0.0	-.831	-1.0	-.782	-.500	.707	.866	.623	0.0	-.556	-1.0	-.707	-.434	.383	.866	1.0	.707	.222	-.145	-.500	-.707	0.0	.739	.523	.194	-1.0	-.844	-.262
	47	-1.0	.777	.918	.998	.931	.574	-.208	-.686	-.991	-.733	-.454	.342	.981	.914	.434	.058	-.966	-.449	-.0747	.588	.947	.766	.052	-.295	-.924	-.958	-.669	.087	.623	.897	.993	.988	-.866	.312	.575	.831	.309	-.273	-.762
	49	1.0	-.839	-.958	-.998	-.866	-.423	.407	.835	.991	.500	.156	-.643	-.981	-.669	0.0	.396	.966	-.116	-.500	-.951	-.947	-.174	.629	.866	.924	.597	-.105	-.819	-1.0	-.897	.690	.454	.866	-.994	-.979	-.831	.809	1.0	.823
	51	-1.0	.891	.985	.981	.782	.259	-.588	-.940	-.924	-.223	.156	.866	.831	.309	-.434	-.766	-.707	.643	.901	.951	.556	-.500	-.988	-.975	-.383	.342	.809	.966	.623	.195	-.174	-.454	0.0	.501	.203	-.194	-.809	-.297	.333
	53	1.0	-.934	-.998	-.947	-.680	-.0872	.743	.993	.793	-.0747	-.454	-.985	-.556	.105	.782	.973	.259	-.958	-.989	-.588	.065	.940	.839	.583	-.383	-.918	-.978	-.423	.222	.660	.894	.988	-.866	.585	.818	.981	-.309	-.721	-.997
	55	-1.0	.966	.998	.897	.563	-.0872	-.866	-.993	-.609	.365	.707	.985	.195	-.500	-.975	.973	.259	.958	.733	0.0	-.659	-.940	-.259	.148	.924	.918	.500	-.423	-.901	-.998	-.894	-.707	.866	-.979	-.853	-.555	1.0	.771	.187
	57	1.0	-.988	-.985	-.831	-.434	.259	.951	.940	.383	-.624	-.891	-.866	.195	.809	.975	.766	-.707	-.643	-.223	.588	.981	.500	-.454	-.782	-.924	-.342	.309	.966	.901	.556	.174	-.156	0.0	.215	-.141	-.555	-.309	.407	.899
	59	-1.0	.999	.958	.756	.295	-.423	-.995	-.835	.131	.826	.988	.643	-.556	-.978	-.782	-.396	.966	.116	-.365	-.951	-.897	.174	.934	.997	.383	-.597	-.914	-.819	-.222	.321	.690	.891	-.866	.803	.965	.981	-.809	-.994	-.777
	61	1.0	-.999	-.978	-.659	-.149	.574	.995	.686	-.131	-.956	-.988	-.342	.831	.978	.434	-.058	-.966	.449	.826	.951	.442	-.766	-.934	-.680	.383	.958	.914	.087	-.623	-.947	-.993	.891	.866	-.872	-.625	-.194	.809	.175	-.557
	63	-1.0	.988	.866	.556	0.0	-.707	-.951	-.500	.383	1.0	.891	0.0	-.981	-.809	0.0	.500	.707	-.866	-1.0	-.588	.195	1.0	.454	0.0	-.924	-.866	-.309	.707	1.0	.831	.500	.156	0.0	-.091	-.468	-.831	.309	.894	.947
	65	1.0	-.966	-.802	-.442	.149	.814	.866	.287	-.609	-.956	-.707	.342	.981	.500	-.434	-.795	-.259	.998	.826	0.0	-.752	-.766	.259	.680	.924	.231	-.500	-.996	-.623	-.065	.396	.707	-.866	.946	.997	.831	-1.0	-.685	.063

TABLE 1

General Effect of Voltage and Frequency Variation on Induction-Motor Characteristics

+ = Increase — = Decrease

		Starting and Maximum Running Torque	Synchronous Speed	% Slip	Full-load Speed	Efficiency			Power Factor			Full-load Current	Starting Current	Temperature Rise, Full Load	Maximum Overload Capacity	Magnetic Noise, No Load in Particular
						Full Load	¾ Load	½ Load	Full Load	¾ Load	½ Load					
Voltage Variation	120% Voltage	+44%	No change	−30%	+ 1.5%	Small +	— ½ to 2 points	— 7 to 20 points	— 5 to 15 points	— 10 to 30 points	— 15 to 40 points	−11%	+25%	— 5 to 6 C	+44%	Noticeable +
	110% Voltage	+21%	No change	−17%	+1%	+ ½ to 1 point	Practically no change	— 1 to 2 points	— 3 points	— 4 points	— 5 to 6 points	−7%	+10 to 12%	— 3 to 4 C	+21%	Slight +
	Function of Voltage	$(\text{Voltage})^2$	Constant	$\frac{1}{(\text{Voltage})^2}$	(Syn speed slip)	—	—	—	—	—	—	—	Voltage	—	$(\text{Voltage})^2$	—
	90% Voltage	−19%	No change	+23%	−1½%	— 2 points	Practically no change	+ 1 to 2 points	+ 1 point	+ 2 to 3 points	+ 4 to 5 points	+11%	— 10 to 12%	+ 6 to 7 C	−19%	Slight —
Frequency Variation	105% Frequency	−10%	+5%	Practically no change	+ 5%	Slight +	Slight +	Slight +	Slight +	Slight +	Slight +	Slight —	— 5 to 6%	Slight —	Slight —	Slight —
	Function of Frequency	$\frac{1}{(\text{Frequency})^2}$	Frequency		(Syn speed slip)	—	—	—	—	—	—	—	$\frac{1}{\text{Frequency}}$	—	—	—
	95% Frequency	+11%	−5%	Practically no change	— 5%	Slight —	Slight —	Slight —	Slight —	Slight —	Slight —	Slight +	+ 5 to 6%	Slight +	Slight +	Slight +

Note: This table shows general effects, which will vary somewhat for specific ratings.

TABLE 2

DATA ON BARE AND INSULATED ROUND COPPER WIRE

BARE WIRE							RESISTANCE - OHMS PER 1000 FT AT			OVER-ALL DIAMETER IN MILS																		
DIAMETER (Inch)		Awg (Reference only)	AREA CROSS SECTION		Pounds per 1000 Ft	Feet per Pound	25 C	75 C	105 C	ENAMEL	FORMEX				COTTON				GLASS						ASBESTOS			CELANESE & NYLON
Nominal	Tolerance ±		Circular Mils	Square Mils						E Single	F Single	HF Heavy	TF Triple	QF Quadruple	C Single Cotton	DC Double Cotton	EC FC Enamel Cotton Formex Cotton	EDC FDC Enamel Double Cotton Formex Double Cotton	G Single Glass Varnish	DG Double Glass Varnish	FG Formex Glass Varnish	FDG Formex Double Glass Varnish	HFG Heavy Formex Glass Varnish	HFDG Heavy Formex Double Glass Varnish	Type A WE	FA FWE Formex Plus Type A or WE	HFA HFWE Heavy Formex Plus Type A or WE	
0.204	0.0020	4	41620	32690	126.0	7.94	0.254	0.303	0.332						212	220			211	217					218			
0.193	0.0019		37250	29260	113.0	8.87	0.284	0.338	0.371						201	209			200	206					207			
0.182	0.0018	5	33120	26010	100.0	9.98	0.319	0.381	0.417						190	198			189	195					196			
0.172	0.0017		29580	23230	89.5	11.2	0.357	0.426	0.467						180	188			179	185					185			Increase Diameter 2.2 Mils per Wrap
0.162	0.0016	6	26240	20610	79.4	12.6	0.403	0.480	0.527						170	176			169	175					175			
0.153	0.0015		23410	18390	70.9	14.1	0.452	0.539	0.591						161	167			160	166					166			
0.144	0.0014	7	20740	16290	62.8	15.9	0.510	0.608	0.667						152	158			151	157					157			
0.136	0.0014		18500	14530	56.0	17.9	0.571	0.682	0.748						144	150			143	149					148			
0.128	0.0013	8	16380	12870	49.6	20.2	0.645	0.770	0.884	130	130	132	133.1	134.8	136	142			135	141	137	143	139	145	140	142	144	
0.121	0.0012		14640	11500	44.3	22.6	0.722	0.862	0.945	123	123	125	126	127.7	129	135			128	134	130	136	132	138	133	135	137	
0.114	0.0011	9	13000	10210	39.4	25.4	0.813	0.970	1.06	116	116	118	119	120.7	121	126			121	127	123	129	125	131	126	128	130	
0.108	0.0011		11660	9161	35.3	28.3	0.907	1.08	1.19	110	110	112	113	114.6	115	120			114	117	116	119	118	121	119	121	123	
0.102	0.0010	10	10400	8170	31.5	31.8	1.02	1.21	1.33	104	104	106	106.9	108.6	108	113	110	115	108	111	110	113	112	115	113	115	117	
0.0961	0.0010		9235	7253	28.0	35.8	1.14	1.37	1.50	97.9	97.9	99.6	100.9	102.5	102	107	104	109	102.1	105.1	103.9	106.9	105.6	108.6	107.1	108.9	110.6	
0.0907	0.0009	11	8230	6460	24.9	40.2	1.29	1.53	1.69	92.5	92.5	94.1	95.4	97.1	95.7	100	97.5	102	96.7	99.7	98.5	101.5	100.1	103.1	101.7	103.5	105.1	
0.0856	0.0009		7327	5755	22.2	45.1	1.44	1.72	1.89	87.4	87.4	88.9	90.2	91.9	90.6	94.6	92.4	96.9	91.6	94.6	93.4	96.4	94.9	97.9	95.6	97.4	98.9	
0.0808	0.0008	12	6530	5130	19.8	50.7	1.62	1.93	2.12	82.5	82.5	84.0	85.3	87.0	85.8	90.3	87.5	92.0	86.8	89.8	88.5	91.5	90.0	93.0	90.8	92.5	94.0	
0.0763	0.0008		5822	4572	17.6	56.8	1.82	2.17	2.38	78.0	78.0	79.4	80.7	82.3	81.3	85.8	83.0	87.5	82.3	85.3	84.0	87.0	85.4	88.4	86.3	88.0	89.4	
0.0720	0.0007	13	5180	4070	15.7	63.8	2.04	2.43	2.67	73.7	73.7	75.1	76.4	77.9	77.0	81.5	78.7	83.2	78.0	81.0	79.7	82.7	81.1	84.1	82.0	83.7	85.1	
0.0679	0.0007		4610	3621	14.0	71.6	2.29	2.74	3.00	69.6	69.6	70.9	72.2	73.7	72.9	77.4	74.6	79.1	73.9	76.9	75.6	78.6	76.9	79.9	77.4	79.1	80.4	
0.0641	0.0006	14	4110	3230	12.4	80.4	2.57	3.07	3.36	65.8	65.8	67.1	68.4	69.9	69.1	73.6	70.8	75.3	70.1	73.1	71.8	74.8	73.0	76.1	73.6	75.3	76.6	
0.0605	0.0006		3660	2875	11.1	90.2	2.89	3.45	3.78	62.2	62.2	63.4	64.7	66.2	65.5	70.0	67.2	71.7	66.5	69.5	68.2	71.2	69.4	72.4	69.5	71.2	72.4	
0.0571	0.0006	15	3260	2560	9.87	101	3.24	3.87	4.24	58.7	58.7	60.0	61.3	62.8	62.1	66.6	63.7	68.2	63.1	66.1	64.7	67.7	66.0	69.0	66.1	67.7	69.0	
0.0538	0.0005		2894	2273	8.76	114	3.65	4.36	4.78	55.4	55.4	56.7	57.9	59.4	58.8	63.3	60.4	64.9	59.8	62.8	61.4	64.4	62.7	65.7	62.3	63.9	65.2	
0.0508	0.0005	16	2580	2030	7.81	128	4.10	4.89	5.36	52.3	52.3	53.7	54.8	56.3	55.8	60.3	57.3	61.8	56.8	59.8	58.3	61.3	59.7	62.7	59.3	60.8	62.2	
0.0480	0.0005		2304	1810	6.97	143	4.59	5.47	6.01	49.5	49.5	50.8	51.9	53.4	53.0	57.5	54.5	59.0	54.0	57.0	55.5	58.5	56.8	59.8	56.5	58.0	59.3	
0.0453	0.0005	17	2060	1610	6.21	161	5.15	6.14	6.74	46.8	46.8	48.1	49.2	50.6	50.3	54.8	51.8	56.3	51.3	54.0	52.8	55.8	54.1	57.1	53.8	55.3	56.6	
0.0427	0.0004		1823	1432	5.52	181	5.80	6.92	7.59	44.2	44.2	45.4	46.5	47.9	47.7	52.2	49.2	53.7	48.7	51.7	50.2	53.2	51.4	54.4	50.7	52.2	53.4	
0.0403	0.0004	18	1620	1280	4.91	204	6.51	7.76	8.51	41.7	41.7	43.0	44.1	45.5	45.3	49.8	46.7	51.2	46.3	49.3	47.7	50.7	49.0	52.0	48.3	49.7	51.0	
0.0380	0.0004		1444	1134	4.37	229	7.32	8.73	9.58	39.4	39.4	40.6	41.7	43.1	43.0	47.5	44.4	48.9	44.0	47.0	45.4	48.4	46.6	49.6	46.0	47.4	48.6	
0.0359	0.0004	19	1290	1012	3.90	256	8.21	9.79	10.7	37.3	37.3	38.5	39.6	40.9	40.9	45.4	42.3	46.8	41.9	44.9	43.3	46.3	44.5	47.5	43.9	45.3	46.5	
0.0339	0.0003		1149	903	3.48	287	9.20	11.0	12.0	35.3	35.3	36.4	37.5	38.8	38.9	43.4	40.3	44.8	39.9	42.9	41.3	44.3	42.4	45.4	41.9	43.3	44.4	
0.0320	0.0003	20	1020	804	3.10	323	10.3	12.3	13.5	33.3	33.3	34.5	35.5	36.8	37.0	41.5	38.3	42.8	38.0	41.0	39.3	42.3	40.5	43.5	40.0	41.3	42.5	
0.0302	0.0003		912	716	2.76	362	11.6	13.8	15.2	31.5	31.5	32.6	33.6	34.9	35.2	39.7	36.5	41.0	36.2	39.2	37.5	40.5	38.6	41.6	38.2	39.5	40.6	
0.0285	0.0003	21	812	638	2.46	407	13.0	15.5	17.0	29.8	29.8	30.9	31.9	33.1	33.5	38.0	34.8	39.3	34.5	37.5	35.8	38.8	36.9	39.9	36.5	37.8	38.9	
0.0253	0.0003	22	640	503	1.94	516	16.5	19.7	21.6	26.5	26.5	27.6	28.5	29.7	29.8	33.8	31.0	35.0	31.3	34.3	32.5	35.5	33.6	36.6	33.3	34.5	35.6	
0.0226	0.0002	23	511	401	1.55	647	20.7	24.7	27.1	23.7	23.7	24.8	25.7	26.9	27.1	31.1	28.2	32.2	28.6	31.6	29.7	32.7	30.8	33.8	30.6	31.7	32.8	
0.0201	0.0002	24	404	317	1.22	818	26.2	31.2	34.3	21.2	21.2	22.2	23.1	24.3	24.6	28.6	25.7	29.7	26.1	29.1	27.2	30.2	28.2	31.2	28.1	29.2	30.2	
0.0179	0.0002	25	320	252	0.970	1031	33.0	39.4	43.2	19.0	19.0	19.9	20.8	21.9	22.4	26.4	23.5	27.5	21.9	23.9	23.0	25.0	23.9	25.9	25.9	27.0	27.9	
0.0159	0.0002	26	253	199	0.765	1307	41.8	49.9	54.7	16.9	16.9	17.8	18.7	19.7	20.4	24.4	21.4	25.4	19.9	21.9	20.9	22.9	21.8	23.8	23.9	24.9	25.8	
0.0142	0.0001	27	202	158	0.610	1639	52.4	62.5	68.5	15.2	15.2	16.0	16.8	17.8	18.7	22.7	19.7	23.7	18.2	20.2	19.2	21.2	20.0	22.0	22.2	23.2	24.0	
0.0126	0.0001	28	159	125	0.481	2081	66.6	79.4	87.1	13.5	13.5	14.3	15.0	15.9	17.1	21.1	18.0	22.0	16.6	18.6	17.5	19.5	18.3	20.3	20.6	21.5	22.3	
0.0113	0.0001	29	128	100	0.387	2587	82.8	98.7	108	12.2	12.2	12.9	13.6	14.5	15.8	19.8	16.7	20.7	15.3	17.3	16.2	18.2	16.9	18.9	19.3	20.2	20.9	
0.0100	0.0001	30	100	78.5	0.303	3304	106	126	139	10.9	10.9	11.5	12.2	13.1	14.5	18.5	15.4	19.4	14.0	16.0	14.9	16.9	15.5	17.5	18.0	18.9	19.5	
0.0089	0.0001	31	79.2	62.2	0.240	4170	134	159	175	9.8	9.8	10.4	11.0	11.8	13.4	17.4	14.1	18.1										
0.0080	0.0001	32	64.0	50.3	0.194	5163	165	197	216	8.8	8.8	9.4	10.0	10.7	12.5	16.5	13.2	17.2										
0.0071	0.0001	33	50.4	39.6	0.153	6553	210	250	275	7.8	7.8	8.4	8.9	9.7	11.6	15.6	12.2	16.2										
0.0063	0.0001	34	39.7	31.2	0.120	8326	266	318	348	7.0	7.0	7.4	7.9	8.6	10.8	14.8	11.4	15.4										
0.0056	0.0001	35	31.4	24.7	0.0949	10530	337	402	441	6.2	6.2	6.6	7.1	7.7	10.1	14.1	10.6	14.6										
0.0050	0.0001	36	25.0	19.6	0.0757	13210	423	504	553	5.6	5.6	5.9	6.4	7.0	9.0	13.0	9.5	13.5										
0.0045	0.0001	37	20.3	15.9	0.0613	16310	521	621	681	5.0	5.0	5.4	5.8	6.3	8.5	12.5	8.9	12.9										
0.0040	0.0001	38	16.0	12.6	0.0484	20650	661	788	865	4.5	4.5	4.8	5.2	5.6	8.0	12.0	8.8	12.8										
0.0035	0.0001	39	12.3	9.7	0.0371	26970	859	1025	1124	3.9	3.9	4.2	4.6	5.0	7.5	11.5	7.8	11.8										
0.0031	0.0001	40	9.6	7.5	0.0291	34380	1101	1313	1440	3.5	3.5	3.8	4.1	4.4	7.1	11.1	7.4	11.4										
0.0028	0.0001	41	7.8	6.1	0.0237	42140	1355	1616	1772	3.1	3.1	3.4																
0.0025	0.0001	42	6.3	4.9	0.0189	52850	1678	2001	2195	2.8	2.8	3.0																
0.0022	0.0001	43	4.8	3.8	0.0146	68260	2185	2606	2860	2.5	2.5	2.7																
0.0020	0.0001	44	4.0	3.1	0.0121	82590	2644	3153	3460	2.3	2.3	2.5																

The figures given for over-all diameter are such that they will not normally be exceeded in wire manufactured for general use. It should be recognized that the variations in over-all wire diameter are less than the sums of the individual variations in the bare wire and the insulation covering, so that the tabulated figures are in most cases smaller than the values obtained by directly adding the maximum permissible wire diameter, and the maximum permissible insulation thickness under NEMA standards.

Through the courtesy
of the
General Electric Company
Schenectady, N.Y.

TABLE 3

Data on Square Bare Copper Wire

Size A.W.G.	Nominal Dimension Mills	Area Square Mills	Area Circular Mills	Weight Pounds Per 1000 Ft.	Length Feet Per Pound	Resistance - - Ohms Per 1000 Ft. at		
						25° C	75° C	105° C
0	324	102093	129984	393	2.54	.0813	.0967	.1059
1	289	80283	102216	309	2.23	.1035	.1231	.1347
2	257	62963	80164	243	4.12	.1319	.1568	.1718
3	229	49223	62670	190	5.27	.1687	.2006	.2197
4	204	39844	50729	154	6.51	.2084	.2478	.2715
5	181	31204	39729	120	8.31	.2661	.3164	.3466
6	162	25425	32371	98	10.2	.3268	.3883	.4253
7	144	19995	25475	77.1	13.0	.4152	.4937	.5408
8	128	15685	19970	60.4	16.5	.5294	.6297	.6895
9	114	12268	15616	47.3	21.2	.6771	.8051	.8819
10	101	9843	12532	37.9	26.4	.8439	1.033	1.099
11	90.7	7697	9800	29.7	23.7	1.078	1.282	1.405
12	80.8	5993	7630	23.1	43.3	1.385	1.647	1.804
13	72.0	4641	5909	17.9	55.9	1.789	2.127	2.330
14	64.1	3570	4545	13.8	72.7	2.326	2.766	3.029

TABLE 4

Nominal Thickness of Insulation Covering (Sum of Two Sides) for Square or Rectangular Wire.

Double Cotton or Double Glass.

Bare Thick.	Bare Width	.021 to .031	.032 to .043	.044 to .057	.058 to .071	.072 to .091	.092 to .115	.116 to .143	.144 to .181	.182 to .228	.229 to .285	.286 to .339	.340 to .500
.021 to .031	T	.009	.009	.010	.010	.010	.011	.011	.012	.013	.014	.015	.016
	W	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.008	.008
.032 to .043	T		.009	.009	.010	.010	.011	.011	.012	.013	.014	.015	.016
	W		.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.008
.044 to .057	T			.009	.010	.010	.011	.011	.012	.013	.014	.015	.016
	W			.009	.009	.009	.009	.009	.009	.009	.009	.009	.009
.058 to .071	T				.009	.010	.011	.011	.012	.013	.014	.015	.016
	W				.009	.009	.010	.010	.010	.010	.010	.009	.009
.072 to .091	T					.010	.010	.011	.012	.013	.014	.015	.016
	W					.010	.010	.010	.010	.010	.010	.010	.010
.092 to .115	T						.011	.012	.013	.014	.015	.016	.016
	W						.011	.011	.011	.011	.011	.011	.011
.116 to .143	T							.013	.014	.015	.016	.018	.018
	W							.013	.013	.013	.013	.013	.013
.144 to .181	T								.015	.016	.017	.019	.020
	W								.015	.015	.015	.015	.015
.182 to .228	T									.017	.019	.020	.021
	W									.017	.017	.017	.017
.229 to .285	T										.019	.020	.021
	W										.019	.019	.018
.286 to .339	T											.020	.021
	W											.020	.020
.340 to .500	T												.021
	W												.021

T = Thickness
W = Width

TABLE 5

Sine Values for 45 to 90 Degrees for use in Figuring Pitch Factors

Degrees	0.0	0.2	0.4	0.6	0.8
45	0.7071	0.7096	0.7120	0.7145	0.7169
46	0.7193	0.7218	0.7242	0.7266	0.7290
47	0.7314	0.7337	0.7361	0.7385	0.7408
48	0.7431	0.7455	0.7478	0.7501	0.7524
49	0.7547	0.7570	0.7593	0.7615	0.7638
50	0.7660	0.7683	0.7705	0.7727	0.7749
51	0.7771	0.7793	0.7815	0.7837	0.7859
52	0.7880	0.7902	0.7923	0.7944	0.7965
53	0.7986	0.8007	0.8028	0.8049	0.8070
54	0.8090	0.8111	0.8131	0.8151	0.8171
55	0.8192	0.8211	0.8231	0.8251	0.8271
56	0.8290	0.8310	0.8329	0.8348	0.8368
57	0.8387	0.8406	0.8425	0.8443	0.8462
58	0.8480	0.8499	0.8517	0.8536	0.8554
59	0.8572	0.8590	0.8607	0.8625	0.8643
60	0.8660	0.8678	0.8695	0.8712	0.8729
61	0.8746	0.8763	0.8780	0.8796	0.8813
62	0.8829	0.8846	0.8862	0.8878	0.8894
63	0.8910	0.8926	0.8942	0.8957	0.8973
64	0.8988	0.9003	0.9018	0.9033	0.9048
65	0.9063	0.9078	0.9092	0.9107	0.9121
66	0.9135	0.9150	0.9164	0.9178	0.9191
67	0.9205	0.9219	0.9232	0.9245	0.9259
68	0.9272	0.9285	0.9298	0.9311	0.9323
69	0.9336	0.9348	0.9361	0.9373	0.9385
70	0.9397	0.9409	0.9421	0.9432	0.9444
71	0.9455	0.9466	0.9478	0.9489	0.9500
72	0.9511	0.9521	0.9532	0.9542	0.9553
73	0.9563	0.9573	0.9583	0.9593	0.9603
74	0.9613	0.9622	0.9632	0.9641	0.9650
75	0.9659	0.9668	0.9677	0.9686	0.9694
76	0.9703	0.9711	0.9720	0.9728	0.9736
77	0.9744	0.9751	0.9759	0.9767	0.9774
78	0.9781	0.9789	0.9796	0.9803	0.9810
79	0.9816	0.9823	0.9829	0.9836	0.9842
80	0.9848	0.9854	0.9860	0.9866	0.9871
81	0.9877	0.9882	0.9888	0.9893	0.9898
82	0.9903	0.9907	0.9912	0.9917	0.9921
83	0.9925	0.9930	0.9934	0.9938	0.9942
84	0.9945	0.9949	0.9952	0.9956	0.9959
85	0.9962	0.9965	0.9968	0.9971	0.9973
86	0.9976	0.9978	0.9980	0.9982	0.9984
87	0.9986	0.9988	0.9990	0.9991	0.9993
88	0.9994	0.9995	0.9996	0.9997	0.9998
89	0.9998	0.9999	0.9999	1.000	1.000

TABLE 6

Approximate Full-Load Currents of Single-Phase Motors

Horsepower	Current in amperes	
	110 volts	220 volts
1/8	2.7	1.35
1/6	3	1.5
1/4	4	2
1/3	5	2.5
1/2	7.5	3.75
3/4	10.5	5.25
1	13	6.5
1 1/2	18	9
2	23	11.5
3	32	16
5	50	25
7 1/2	70	35
10	94	47

TABLE 7

Approximate Operating Data for Constant Speed Squirrel Cage Induction Motors from 1/2 Horsepower to 200 Horsepower

HP	No. of Poles	RPM		Efficiency Full Load	Power Factor Full Load	Amperes Full Load (440 Volts)
		Syn.	Full Load			
1/2	8	900	875	68	58	1.2
3/4	6	1200	1160	72	69	1.5
	8	900	875	71	58	1.8
	10	720	690	68	57	1.9
	12	600	575	65	56	2.0
1	4	1800	1750	79	79	1.6
	6	1200	1160	76	70	1.8
	8	900	875	74	62	2.1
	10	720	690	72	60	2.3
	12	600	575	68	58	2.5
2	2	3600	3525	83	86	2.7
	4	1800	1750	81	80	3.0
	6	1200	1165	81	71	3.4
	8	900	878	75	66	3.9
	10	720	693	72	62	4.4
	12	600	580	68	60	4.8
3	2	3600	3530	84	87	4.0
	4	1800	1755	84	82	4.3
	6	1200	1168	82	77	4.6
	8	900	880	82	68	5.3
	10	720	693	79	64	5.8
	12	600	580	75	61	6.4
5	2	3600	3530	85	88	6.5
	4	1800	1755	85	83	6.9
	6	1200	1170	83	79	7.5
	8	900	880	83	73	8.1
	10	720	695	82	67	8.9
7 1/2	2	3600	3535	85	88	9.8
	4	1800	1755	86	84	10.2
	6	1200	1170	84	82	10.7
	8	900	883	84	75	11.7
	10	720	695	83	70	12.7
10	2	3600	3535	85	88	13.2
	4	1800	1755	86	87	13.2
	6	1200	1170	87	85	13.5
	8	900	883	87	82	13.7
	10	720	695	85	75	15.5
15	2	3600	3535	85	88	20
	4	1800	1760	87	89	19
	6	1200	1170	88	87	19
	8	900	885	88	83	20
	10	720	695	86	78	22
20	2	3600	3540	86	88	26
	4	1800	1760	89	89	25
	6	1200	1170	89	87	25
	8	900	885	88	84	26
	10	720	695	86	79	29
25	2	3600	3540	87	88	33
	4	1800	1765	89	89	31
	6	1200	1170	89	87	32
	8	900	885	88	84	33
	10	720	695	86	79	36
30	2	3600	3540	88	88	38
	4	1800	1765	90	89	37
	6	1200	1170	89	87	38
	8	900	885	89	85	39
	10	720	695	87	80	42

TABLE 7 - Continued

Approximate Operating Data for Constant Speed Squirrel Cage Induction Motors from 1/2 Horsepower to 200 Horsepower

HP	No. of Poles	RPM		Efficiency Full Load	Power Factor Full Load	Amperes Full Load (440 Volts)
		Syn.	Full Load			
40	2	3600	3540	89	88	50
	4	1800	1765	91	90	48
	6	1200	1170	90	87	50
	8	900	885	90	85	51
	10	720	695	88	82	54
50	2	3600	3540	90	88	62
	4	1800	1765	91	90	61
	6	1200	1175	90	88	62
	8	900	885	90	88	62
	10	720	695	89	83	66
60	2	3600	3545	90	87	75
	4	1800	1765	91	90	72
	6	1200	1180	91	88	73
	8	900	885	91	88	73
	10	720	695	90	83	79
75	2	3600	3550	91	88	92
	4	1800	1770	91	90	90
	6	1200	1180	91	88	92
	8	900	885	91	88	92
	10	720	695	90	83	98
100	2	3600	3550	92	87	123
	4	1800	1775	91	90	120
	6	1200	1180	91	88	123
	8	900	885	91	88	123
	10	720	700	90	83	131
125	2	3600	3550	92	87	153
	4	1800	1775	91	89	151
	6	1200	1180	91	88	153
	8	900	885	91	87	155
	10	720	705	91	85	158
150	2	3600	3550	93	87	182
	4	1800	1780	92	89	180
	6	1200	1185	92	88	182
	8	900	885	92	87	184
	10	720	705	91	85	190
200	2	3600	3550	93	87	242
	4	1800	1780	92	89	240
	6	1200	1185	92	88	242
	8	900	885	92	87	245
	10	720	705	91	85	254

Note: - Values of full load RPM, efficiency and power factor are approximate values. Full load amperes at voltages other than 440 volts will be inversely proportional to the values shown for 440 volts.

TABLE 8

Approximate Operating Data for Constant Speed Squirrel Cage Induction Motors and for Wound Rotor Induction Motors from 250 to 1000 Horsepower

HP	No. of Poles	SYN. RPM	SQUIRREL CAGE MOTORS				WOUND ROTOR MOTORS			
			Approx. Full Load RPM	Efficiency Full Load	Power Factor Full Load	Amperes Full Load 2300 volts	Approx. Full Load RPM	Efficiency Full Load	Power Factor Full Load	Amperes Full Load 2300 volts
250	2	3600	3540	93	87	58	-	-	-	-
	4	1800	1775	93	89	57	1775	93	88	57
	6	1200	1180	92	88	58	1180	92	86	59
	8	900	870	92	87	58	870	92	84	61
	10	720	695	92	85	60	695	92	83	62
	12	600	580	91	83	62	580	91	79	65
	14	514	496	91	82	63	496	91	76	68
	16	450	-	91	80	64	-	91	73	71
	18	400	-	90	78	67	-	90	69	75
	20	360	-	90	76	68	-	90	66	79
	22	327	-	90	74	70	-	90	64	81
	24	300	-	89	73	71	-	89	60	87
300	2	3600	3540	93	88	69	-	-	-	-
	4	1800	1775	93	90	67	1775	93	89	68
	6	1200	1180	92	89	69	1180	92	87	70
	8	900	873	92	87	70	873	92	85	72
	10	720	698	92	86	71	698	92	83	74
	12	600	580	92	84	73	580	92	80	76
	14	514	497	91	83	74	497	91	77	80
	16	450	-	91	81	75	-	91	75	82
	18	400	-	91	79	78	-	91	71	87
	20	360	-	91	78	79	-	91	67	92
	22	327	-	90	77	81	-	90	64	98
	24	300	-	90	76	82	-	90	61	102
350	2	3600	3550	94	89	78	-	-	-	-
	4	1800	1777	94	90	77	1777	94	89	78
	6	1200	1180	94	89	78	1180	94	87	80
	8	900	878	93	87	81	878	93	85	83
	10	720	700	92	86	83	700	92	83	86
	12	600	582	92	85	84	582	92	81	88
	14	514	498	92	84	85	498	92	78	91
	16	450	-	92	82	87	-	92	75	95
	18	400	-	91	80	90	-	91	71	101
	20	360	-	91	79	91	-	91	68	106
	22	327	-	91	77	93	-	91	65	111
	24	300	-	90	76	95	-	90	61	118
400	2	3600	3550	94	88	90	-	-	-	-
	4	1800	1777	93	90	90	1777	93	88	92
	6	1200	1180	93	89	91	1180	93	88	92
	8	900	879	93	88	92	879	93	86	94
	10	720	700	93	86	94	700	93	84	96
	12	600	582	92	85	96	582	92	81	100
	14	514	498	92	84	97	498	92	79	103
	16	450	-	92	83	98	-	92	76	107
	18	400	-	92	81	100	-	92	72	113
	20	360	-	91	80	103	-	91	69	119
	22	327	-	91	78	106	-	91	65	127
	24	300	-	90	77	108	-	90	62	134
450	2	3600	3555	94	89	101	-	-	-	-
	4	1800	1778	93	90	101	1778	93	89	102
	6	1200	1180	93	89	102	1180	93	87	104
	8	900	879	93	88	103	879	93	86	105
	10	720	700	93	87	104	700	93	84	108
	12	600	583	92	86	107	583	92	82	112
	14	514	498	92	85	108	498	92	79	116
	16	450	-	92	83	110	-	92	76	120
	18	400	-	92	81	113	-	92	72	127
	20	360	-	91	80	116	-	91	69	134
	22	327	-	91	78	119	-	91	66	141
	24	300	-	91	77	120	-	91	62	149

TABLE 8 - Continued

Approximate Operating Data for Constant Speed Squirrel Cage Induction Motors and for Wound Rotor Induction Motors from 250 to 1000 Horsepower

HP	No. of Poles	SYN. RPM	SQUIRREL CAGE MOTORS				WOUND ROTOR MOTORS			
			Approx. Full Load RPM	Efficiency Full Load	Power Factor Full Load	Amperes Full Load 2300 volts	Approx. Full Load RPM	Efficiency Full Load	Power Factor Full Load	Amperes Full Load 2300 volts
500	2	3600	3560	94	87	115	-	-	-	-
	4	1800	1780	93	90	112	1780	93	89	112
	6	1200	1181	93	89	112	1181	93	88	114
	8	900	880	93	88	114	880	93	86	117
	10	720	700	93	87	116	700	93	85	119
	12	600	583	93	86	117	583	93	82	123
	14	514	498	92	85	119	498	92	80	127
	16	450	-	92	83	123	-	92	76	134
	18	400	-	92	82	124	-	92	73	140
	20	360	-	92	80	127	-	92	70	145
	22	327	-	91	79	130	-	91	66	156
	24	300	-	91	78	132	-	91	63	163
600	2	3600	3565	94	89	134	-	-	-	-
	4	1800	1780	93	90	134	1780	93	90	134
	6	1200	1181	93	90	134	1181	93	88	137
	8	900	879	93	89	136	879	93	87	139
	10	720	701	93	88	137	701	93	85	142
	12	600	582	93	87	139	582	93	83	146
	14	514	500	93	86	141	500	93	81	150
	16	450	-	92	84	146	-	92	77	159
	18	400	-	92	83	148	-	92	74	166
	20	360	-	92	81	151	-	92	70	175
	22	327	-	92	80	153	-	92	67	183
	24	300	-	91	79	157	-	91	64	193
700	2	3600	3565	94	89	156	-	-	-	-
	4	1800	1782	94	91	153	1782	94	90	155
	6	1200	1181	94	90	155	1181	94	88	158
	8	900	879	94	89	156	879	94	87	160
	10	720	701	93	88	160	701	93	85	166
	12	600	584	93	87	161	584	93	83	170
	14	514	500	93	87	162	500	93	81	174
	16	450	-	93	85	166	-	93	78	181
	18	400	-	93	83	170	-	93	74	190
	20	360	-	92	82	174	-	92	71	200
	22	327	-	92	80	178	-	92	67	213
	24	300	-	92	79	180	-	92	64	223
800	2	3600	3568	95	90	175	-	-	-	-
	4	1800	1784	94	91	175	1784	94	90	177
	6	1200	1182	94	90	177	1182	94	89	179
	8	900	880	94	89	179	880	94	87	183
	10	720	701	93	88	183	701	93	86	187
	12	600	584	93	88	183	584	93	84	192
	14	514	500	93	87	185	500	93	81	199
	16	450	-	93	85	190	-	93	78	207
	18	400	-	93	84	192	-	93	74	218
	20	360	-	92	82	198	-	92	71	229
	22	327	-	92	81	201	-	92	68	240
	24	300	-	92	80	204	-	92	65	250
900	2	3600	3568	95	91	195	-	-	-	-
	4	1800	1785	94	91	197	1785	94	90	199
	6	1200	1182	94	90	199	1182	94	89	202
	8	900	880	94	89	202	880	94	87	206
	10	720	702	94	89	202	702	94	86	208
	12	600	585	93	88	206	585	93	84	216
	14	514	500	93	87	208	500	93	81	224
	16	450	-	93	85	213	-	93	78	232
	18	400	-	93	84	216	-	93	75	242
	20	360	-	93	83	218	-	93	72	252
	22	327	-	92	82	224	-	92	68	270
	24	300	-	92	80	229	-	92	65	282

TABLE 8 - Continued

Approximate Operating Data for Constant Speed Squirrel Cage Induction Motors and for Wound Rotor Induction Motors from 250 to 1000 Horsepower

HP	No. of Poles	SYN. RPM	SQUIRREL CAGE MOTORS				WOUND ROTOR MOTORS			
			Approx. Full Load RPM	Efficiency Full Load	Power Factor Full Load	Amperes Full Load 2300 volts	Approx. Full Load RPM	Efficiency Full Load	Power Factor Full Load	Amperes Full Load 2300 volts
1000	2	3600	3570	95	91	217	-	-	-	-
	4	1800	1785	94	91	219	1785	94	90	222
	6	1200	1182	94	90	222	1182	94	89	224
	8	900	882	94	90	222	882	94	87	229
	10	720	702	94	89	224	702	94	86	232
	12	600	585	94	88	226	585	94	84	238
	14	514	500	93	87	230	500	93	82	246
	16	450	-	93	86	234	-	93	78	258
	18	400	-	93	84	240	-	93	75	268
	20	360	-	93	82	246	-	93	72	280
	22	327	-	92	81	252	-	92	69	296
	24	300	-	92	81	252	-	92	66	309

Note: - Values of efficiency and power factor are approximate values. Full load amperes at voltages other than 2300 volts will be inversely proportional to the values shown for 2300 volts.

LIST OF SYMBOLS

A, a

A	phase A*
a	smallest integer which makes y an integer

B

B	phase B*

C

C	phase C*
C	equalizer connection
ccw	counter clockwise
cw	clockwise

D, d

D	diameter of stator bore
D'	diameter at which leads of laping winding lie
D	difference between 2 slots which correspond to 2 adjacent vectors of the slot star
d	denominator of the fraction of spp
d	number of poles in a repeatable part of the winding

F

F	finish of a pole phase group

H

HP	horsepower

I

I	integral part of the fractional number of spp

J

J	Jumper

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*Odd subscripts indicate the starts of winding parts; even subscripts indicate their ends. For example, A_1 is the start of the first winding part, A_2 is its end; A_3 is the start of the second winding part, A_4 is its end, and so forth.

LIST OF SYMBOLS

k

k	number of angles α_m by which one layer of a winding is shifted with respect to the other layer, or by which two repeatable groups are shifted with respect to each other
k_d	distribution factor of the main wave
k_{dn}	distribution factor of the n-th harmonic
$k_{dn'}$	distribution factor of the n'-th harmonic
k_p	pitch factor of the main wave
k_{pn}	pitch factor of the n-th harmonic
$k_{pn'}$	pitch factor of the n'-th harmonic
k_2	any positive or negative even integer including zero

L

L	axial length of stator core
LP	long pitch or progressive connection
LP-SP	long pitch-short pitch or progressive-retrogressive connection

m

m	number of phases
m	harmonics produced by 3 phase 6 zone integral slot rotor windings
m'	harmonics produced by 3 phase 6 zone balanced fractional-slot rotor windings

N, n

N	numerator of the fraction spp
N'	number of slot units
N_c	number of turns in the coils of a single phase winding
n	numerator of the fractional part of spp
n	order of the harmonics of integral-slot windings
n'	order of the harmonics of balanced fractional slot windings

P, p

P	number of full pole pitches between 2 slots which correspond to 2 adjacent vectors of the slot star
P	smallest integer, including zero, which makes D an integer
p	number of poles

LIST OF SYMBOLS

q

q	slots per pole per phase

rpm

rpm	revolutions per minute

S, s

S	total number of slots
S	start of a pole phase group
S_p	number of slots per pole of a single phase winding
SP	short pitch or retrogressive connection
spp	slots per pole per phase

T

T	start or end of a phase
T	line lead
t	largest common divisor of number of poles and the number of slots
t	pole pitch in units of W

W

W	coil width

y

y	winding pitch
y_b	back pitch
y_f	front pitch

Z

Z	coil width in slot pitches

α_m	magnetic field angle, or angle between 2 adjacent vectors of the slot star
α_s	angle between 2 slots
φ	angle between phase vectors
→	connected to start or finish of a group
‖	spot for change with respect to series connection, connection tables, 3 phase windings.

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INDEX OF DIAGRAMS

INDEX FOR 2-PHASE TOP-TO-TOP CONNECTION DIAGRAMS FOR LAP WINDINGS

NO. OF POLES	TYPE OF CONNECTION	FIGURE NO.	PAGE
2	Series	3-10	89
	2-Parallel	3-11	89
	Series or 2-Parallel	3-12	91
4	Series	3-13	91
	2-Parallel	3-14	92
	4-Parallel	3-15	92
	Series or 2-Parallel	3-16	93
	2-or 4-Parallel	3-17	93
6	Series	3-18	95
	2-Parallel	3-19	95
	3-Parallel	3-20	96
	6-Parallel	3-21	96
	Series or 2-Parallel	3-22	97
	3-or 6-Parallel	3-23	98
8	Series	3-24	99
	2-Parallel	3-25	99
	4-Parallel	3-26	100
	8-Parallel	3-27	100
	Series or 2-Parallel	3-28	101
	2- or 4-Parallel	3-29	101
	4- or 8-Parallel	3-30	102

INDEX FOR 3 PHASE TOP-TO-BOTTOM CONNECTION DIAGRAMS FOR LAP WINDINGS

NO. OF POLES	TYPE OF CONNECTION	FIGURE NO.	PAGE
4	Series Star	3-31	104
	2-Parallel Star	3-32	105
	Series or 2-Parallel Star	3-33	106
4	Series Delta	3-34	107
	2-Parallel Delta	3-35	108
	Series or 2-Parallel Delta	3-36	109

INDEX FOR 3-PHASE TOP-TO-TOP CONNECTION DIAGRAMS FOR LAP WINDINGS

NO. OF POLES	TYPE OF CONNECTION	FIGURE NO.	PAGE
2	Series Star	3-37	110
	2-Parallel Star	3-38	110
	Series or 2-Parallel Star	3-39	111
	Series Delta	3-40	111
	2-Parallel Delta	3-41	112
	Series or 2-Parallel Delta	3-42	112
4	Series Star	3-43	114
	2-Parallel Star	3-44	114
	4-Parallel Star	3-45	115
	Series or 2-Parallel Star	3-46	115
	2-or 4-Parallel Star	3-47	116
	Series Delta	3-48	116
	2-Parallel Delta	3-49	117
	4-Parallel Delta	3-50	117
	Series or 2-Parallel Delta	3-51	118
	2-or 4-Parallel Delta	3-52	120

INDEX FOR 3-PHASE TOP-TO-TOP CONNECTION DIAGRAMS FOR LAP WINDINGS

NO. OF POLES	TYPE OF CONNECTION	FIGURE NO.	PAGE
6	Series Star	3-53	120
	2-Parallel Star	3-54	121
	3-Parallel Star	3-55	122
	6-Parallel Star	3-56	123
	Series or 2-Parallel Star	3-57	124
	3- or 6-Parallel Star	3-58	125
	Series Delta	3-59	126
	2-Parallel Delta	3-60	126
	3-Parallel Delta	3-61	127
	6-Parallel Delta	3-62	127
	Series or 2-Parallel Delta	3-63	128
	3- or 6-Parallel Delta	3-64	129
8	Series Star	3-65	131
	2-Parallel Star	3-66	132
	4-Parallel Star	3-67	133
	8-Parallel Star	3-68	134
	Series or 2-Parallel Star	3-69	135
	2- or 4-Parallel Star	3-70	136
	4- or 8-Parallel Star	3-71	137
	Series Delta	3-72	138
	2-Parallel Delta	3-73	139
	4-Parallel Delta	3-74	140
	8-Parallel Delta	3-75	141
	Series or 2-Parallel Delta	3-76	142
	2- or 4-Parallel Delta	3-77	143
	4- or 8-Parallel Delta	3-78	144
10	Series Star	3-79	146
	2-Parallel Star	3-80	147
	5-Parallel Star	3-81	148
	10-Parallel Star	3-82	149
	Series or 2-Parallel Star	3-83	150
	5- or 10-Parallel Star	3-84	151
	Series Delta	3-85	152
	2-Parallel Delta	3-86	153
	5-Parallel Delta	3-87	154
	10-Parallel Delta	3-88	155
	Series or 2-Parallel Delta	3-89	156
	5- or 10-Parallel Delta	3-90	157
12	Series Star	3-91	158
	2-Parallel Star	3-92	159
	3-Parallel Star	3-93	160
	4-Parallel Star	3-94	161
	6-Parallel Star	3-95	162
	12-Parallel Star	3-96	163
	Series or 2-Parallel Star	3-97	164
	2- or 4-Parallel Star	3-98	165
	3- or 6-Parallel Star	3-99	166
	6- or 12-Parallel Star	3-100	167
	Series Delta	3-101	168
	2-Parallel Delta	3-102	169
	3-Parallel Delta	3-103	170
	4-Parallel Delta	3-104	171
	6-Parallel Delta	3-105	172
	12-Parallel Delta	3-106	173
	Series or 2-Parallel Delta	3-107	174
	2- or 4-Parallel Delta	3-108	175
	3- or 6-Parallel Delta	3-109	176
	6- or 12-Parallel Delta	3-110	177

INDEX FOR 3-PHASE TOP-TO-TOP CONNECTION DIAGRAMS FOR LAP WINDINGS

NO. OF POLES	TYPE OF CONNECTION	FIGURE NO.	PAGE
14	Series Star	3-111	179
	2-Parallel Star	3-112	180
	7-Parallel Star	3-113	181
	14-Parallel Star	3-114	182
	Series or 2-Parallel Star	3-115	183
	7- or 14-Parallel Star	3-116	184
	Series Delta	3-117	185
	2-Parallel Delta	3-118	186
	7-Parallel Delta	3-119	187
	14-Parallel Delta	3-120	188
	Series or 2-Parallel Delta	3-121	189
	7- or 14-Parallel Delta	3-122	190

INDEX FOR 3 PHASE CONNECTION DIAGRAMS FOR LAP WINDINGS FOR A SPEED RATIO OF 2 TO 1

POLE RATIO	TYPE	HIGH SPEED CONNECTION	LOW SPEED CONNECTION	FIGURE NO.	PAGE
4/8	Constant Horsepower	2-Parallel Star	Series Delta	9-4	571
	Constant Torque	Series Delta	2-Parallel Star	9-5	572
	Variable Torque	Series Star	2-Parallel Star	9-6	573
	Constant Torque	2-Parallel Delta	4-Parallel Star	9-19	586
6/12	Constant Horsepower	2-Parallel Star	Series Delta	9-7	574
	Constant Torque	Series Delta	2-Parallel Star	9-8	575
	Variable Torque	Series Star	2-Parallel Star	9-9	576
8/16	Constant Horsepower	2-Parallel Star	Series Delta	9-10	577
	Constant Torque	Series Delta	2-Parallel Star	9-11	578
	Variable Torque	Series Star	2-Parallel Star	9-12	579
10/20	Constant Horsepower	2-Parallel Star	Series Delta	9-13	580
	Constant Torque	Series Delta	2-Parallel Star	9-14	581
	Variable Torque	Series Star	2-Parallel Star	9-15	582
12/24	Constant Horsepower	2-Parallel Star	Series Delta	9-16	583
	Constant Torque	Series Delta	2-Parallel Star	9-17	584
	Variable Torque	Series Star	2-Parallel Star	9-18	585

INDEX FOR 3-PHASE WORKING DIAGRAMS FOR WAVE WINDINGS

NO. OF POLES	NO. OF SLOTS	TYPE OF CONNECTION	FIGURE NO.	PAGE
6	36	Integral-Slot. Retrogressive.	6-17	321
	36	Integral-Slot. Progressive-Retrogressive	6-65	345
	42	Unbalanced Fractional-Slot.	8-1	531
	45	(Integral + 1/2)-Slot. Retrogressive	6-18	321
	45	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-66	345
	48	Unbalanced Fractional-Slot	8-8	539
	54	Integral-Slot. Retrogressive	6-19	322
	54	Integral-Slot. Progressive-Retrogressive	6-67	346
	63	(Integral + 1/2)-Slot. Retrogressive	6-20	322
	63	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-68	346

INDEX FOR 3-PHASE WORKING DIAGRAMS FOR WAVE WINDINGS

NO. OF POLES	NO. OF SLOTS	TYPE OF CONNECTION	FIGURE NO.	PAGE
6 Cont'd	72	Integral-Slot. Retrogressive	6-21	323
	72	Integral-Slot. Progressive-Retrogressive	6-69	347
	81	(Integral + 1/2)-Slot. Retrogressive	6-22	323
	81	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-70	347
	90	Integral-Slot. Retrogressive.	6-23	324
	90	Integral-Slot. Progressive-Retrogressive	6-71	348
	96	Unbalanced Fractional-Slot	8-6	537
	105	Unbalanced Fractional-Slot	8-17	550
	108	(Integral + 1/2)-Slot. Retrogressive	6-24	324
	108	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-72	348
8	48	Integral-Slot. Retrogressive	6-25	325
	48	Integral-Slot. Progressive-Retrogressive	6-73	349
	54	Balanced Fractional-Slot	7-17	454
	57	Balanced Fractional-Slot	7-33	485
	60	(Integral + 1/2)-Slot. Retrogressive	6-26	325
	60	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-74	349
	63	Balanced Fractional-Slot.	7-38	492
	72	Integral-Slot. Retrogressive	6-27	326
	72	Integral-Slot. Progressive-Retrogressive	6-75	350
	84	(Integral + 1/2)-Slot. Retrogressive	6-28	326
	84	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-76	350
	90	Balanced Fractional-Slot	7-22	464
	96	Integral-Slot. Retrogressive	6-29	327
	96	Integral-Slot. Progressive-Retrogressive	6-77	351
	105	Balanced Fractional-Slot	7-36	490
	108	(Integral + 1/2)-Slot. Retrogressive	6-30	327
	108	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-78	351
	120	Integral-Slot. Retrogressive	6-31	328
	120	Integral-Slot. Progressive-Retrogressive	6-79	352
	126	Balanced Fractional-Slot	7-20	460
	135	Balanced Fractional-Slot	7-41	498
	150	Balanced Fractional-Slot	7-21	462
10	60	Integral-Slot. Retrogressive	6-32	328
	60	Integral-Slot. Progressive-Retrogressive	6-80	352
	72	Balanced Fractional-Slot	7-25	470
	75	(Integral + 1/2)-Slot. Retrogressive	6-33	329
	75	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-81	353
	84	Balanced Fractional-Slot	7-1	434
	90	Integral-Slot. Retrogressive	6-34	329
	90	Integral-Slot. Progressive-Retrogressive	6-82	353
	96	Balanced Fractional-Slot	7-4	438
	105	(Integral + 1/2)-Slot. Retrogressive	6-35	330
	105	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-83	354
	120	Integral-Slot. Retrogressive	6-36	330
	120	Integral-Slot. Progressive-Retrogressive	6-84	354
	135	(Integral + 1/2)-Slot. Retrogressive	6-37	331
	135	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-85	355
	144	Balanced Fractional-Slot	7-3	436
	168	Balanced Fractional-Slot	7-28	475
	192	Balanced Fractional-Slot	7-27	474
12	66	Unbalanced Fractional-Slot	8-11	542
	72	Integral-Slot. Retrogressive	6-38	331
	72	Integral-Slot. Progressive-Retrogressive	6-86	355
	78	Unbalanced Fractional-Slot	8-13	544
	81	Balanced Fractional-Slot	7-18	456
	84	Unbalanced Fractional-Slot	8-2	532
	90	(Integral + 1/2)-Slot. Retrogressive	6-39	332
	90	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-87	356
	96	Unbalanced Fractional-Slot	8-9	540
	102	Unbalanced Fractional-Slot	8-15	548

INDEX FOR 3-PHASE WORKING DIAGRAMS FOR WAVE WINDINGS

NO. OF POLES	NO. OF SLOTS	TYPE OF CONNECTION	FIGURE NO.	PAGE
12 Cont'd	108	Integral-Slot. Retrogressive	6-40	332
	108	Integral-Slot. Progressive-Retrogressive	6-88	356
	120	Unbalanced Fractional-Slot	8-4	535
	126	(Integral + 1/2)-Slot. Retrogressive	6-41	333
	126	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-89	357
	135	Balanced Fractional-Slot	7-23	466
	144	Integral-Slot. Retrogressive	6-42	333
	144	Integral-Slot. Progressive-Retrogressive	6-90	357
	192	Unbalanced Fractional-Slot	8-7	538
	210	Unbalanced Fractional-Slot	8-18	552
14	84	Integral-Slot. Retrogressive	6-43	334
	84	Integral-Slot. Progressive-Retrogressive	6-91	358
	90	Balanced Fractional-Slot	7-6	442
	96	Balanced Fractional-Slot	7-30	480
	105	(Integral + 1/2)-Slot. Retrogressive	6-44	334
	105	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-92	358
	120	Balanced Fractional-Slot	7-9	446
	126	Integral-Slot. Retrogressive	6-45	335
	126	Integral-Slot. Progressive-Retrogressive	6-93	359
	147	(Integral + 1/2)-Slot. Retrogressive	6-46	335
	147	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-94	359
	168	Integral-Slot. Retrogressive	6-47	336
	168	Integral-Slot. Progressive-Retrogressive	6-95	360
	180	Balanced Fractional-Slot	7-32	484
	240	Balanced Fractional-Slot	7-8	445
16	96	Integral-Slot. Retrogressive	6-48	336
	96	Integral-Slot. Progressive-Retrogressive	6-97	360
	108	Balanced Fractional-Slot	7-19	458
	114	Balanced Fractional-Slot	7-34	486
	120	(Integral + 1/2)-Slot. Retrogressive	6-49	337
	120	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-97	361
	126	Balanced Fractional-Slot	7-39	494
	144	Integral-Slot. Retrogressive	6-50	337
	144	Integral-Slot. Progressive-Retrogressive	6-98	361
	168	(Integral + 1/2)-Slot. Retrogressive	6-51	338
	168	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-99	362
	180	Balanced Fractional-Slot	7-24	468
	210	Balanced Fractional-Slot	7-37	491
18	96	Unbalanced Fractional-Slot	8-19	554
	99	Unbalanced Fractional-Slot	8-12	543
	108	Integral-Slot. Retrogressive	6-52	338
	108	Integral-Slot. Progressive-Retrogressive	6-100	362
	114	Unbalanced Fractional-Slot	8-20	556
	117	Unbalanced Fractional-Slot	8-14	546
	126	Unbalanced Fractional-Slot	8-3	534
	132	Unbalanced Fractional-Slot	8-21	558
	135	(Integral + 1/2)-Slot. Retrogressive	6-53	339
	135	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-101	363
	138	Unbalanced Fractional-Slot	8-22	560
	144	Unbalanced Fractional-Slot	8-10	541
	150	Unbalanced Fractional-Slot	8-23	562
	153	Unbalanced Fractional-Slot	8-16	549
	162	Integral-Slot. Retrogressive	6-54	339
	162	Integral-Slot. Progressive-Retrogressive	6-102	363
	189	(Integral + 1/2)-Slot. Retrogressive	6-55	340
	189	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-103	364
20	120	Integral-Slot. Retrogressive	6-56	340
	120	Integral-Slot. Progressive-Retrogressive	6-104	364
	144	Balanced Fractional-Slot	7-26	472

INDEX FOR 3-PHASE WORKING DIAGRAMS FOR WAVE WINDINGS

NO. OF POLES	NO. OF SLOTS	TYPE OF CONNECTION	FIGURE NO.	PAGE
20 Cont'd	150	(Integral + 1/2)-Slot. Retrogressive	6-57	341
	150	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-105	365
	168	Balanced Fractional-Slot	7-2	435
	180	Integral-Slot. Retrogressive	6-58	341
	180	Integral-Slot. Progressive-Retrogressive	6-106	365
	192	Balanced Fractional-Slot	7-5	440
	336	Balanced Fractional-Slot	7-29	476
22	120	Balanced Fractional-Slot	7-11	448
	132	Integral Slot. Retrogressive	6-59	342
	132	Integral Slot. Progressive-Retrogressive	6-107	366
	144	Balanced Fractional-Slot	7-12	449
	165	(Integral + 1/2)-Slot. Retrogressive	6-60	342
	165	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-108	366
	198	Integral-Slot. Retrogressive	6-61	343
	198	Integral-Slot. Progressive-Retrogressive	6-109	367
	240	Balanced Fractional-Slot	7-13	450
24	144	Integral-Slot. Retrogressive	6-62	343
	144	Integral-Slot. Progressive-Retrogressive	6-110	367
	171	Balanced Fractional-Slot	7-35	488
	180	(Integral + 1/2)-Slot. Retrogressive	6-63	344
	180	(Integral + 1/2)-Slot. Progressive-Retrogressive	6-111	368
	189	Balanced Fractional-Slot	7-40	496
	216	Integral-Slot. Retrogressive	6-64	344
	216	Integral-Slot. Progressive-Retrogressive	6-112	368
	240	Unbalanced Fractional-Slot	8-5	536
26	132	Balanced Fractional-Slot	7-42	499
	144	Balanced Fractional-Slot	7-14	451
	168	Balanced Fractional-Slot	7-15	452
	336	Balanced Fractional-Slot	7-16	453
28	180	Balanced Fractional-Slot	7-7	444
	192	Balanced Fractional-Slot	7-31	482
	240	Balanced Fractional-Slot	7-10	447

INDEX TO SINGLE-PHASE CONNECTION DIAGRAMS

NO. OF POLES	TYPE OF CONNECTION		FIGURE NO.	PAGE
	MAIN WINDING	AUXILIARY WINDING		
2	Series	Series	11-11	651
	2-Parallel	Series	11-12	651
4	Series	Series	11-13	652
	2-Parallel	Series	11-14	652
	2-Parallel	2-Parallel	11-15	653
6	Series	Series	11-16	653
	2-Parallel	Series	11-17	654
	2-Parallel	2-Parallel	11-18	654
8	Series	Series	11-19	655
	2-Parallel	Series	11-20	655
	2-Parallel	2-Parallel	11-21	656
10	Series	Series	11-22	656
	2-Parallel	Series	11-23	657
	2-Parallel	2-Parallel	11-24	657

INDEX TO SINGLE-PHASE CONNECTION DIAGRAMS

NO. OF POLES	TYPE OF CONNECTION		FIGURE NO.	PAGE
	MAIN WINDING	AUXILIARY WINDING		
4 and 6	2 Speeds with 2 Winding Sets		11-33	638
4	2 Speeds with Tapped Winding. L - Connected		11-37	641
6	2 Speeds with Tapped Winding. L - Connected		11-39	643

INDEX FOR SINGLE-PHASE WIRING AND LINE CONNECTION DIAGRAMS

FIGURE NO.	DESCRIPTION	PAGE
11-27	Wiring Diagram for plain reversible split-phase motor with 4 leads.	631
11-28	Line Connection Diagram for Figure 11-27.	631
11-29	Wiring Diagram of a non-reversible reactor start, split-phase motor with 2 leads.	633
11-30	Wiring Diagram of a reversible capacitor - start motor with 4 leads.	633
11-31a	Wiring Diagram of a reversible 2-value capacitor motor with transformer unit.	635
11-31b	Wiring Diagram of a reversible 2-value capacitor motor with 2 capacitors.	635
11-32a	Wiring Diagram of a non reversible dual voltage, split-phase motor.	636
11-32b	Line Connection Diagram to Figure 11-32a.	636
11-34	Wiring and Line Connection Diagram for a 2 speed, 2 winding, split-phase motor.	640
11-35	Schematic L - Connection of the 3 Windings of a 2 speed motor.	640
11-36	Schematic T - Connection of the 3 Windings of a 2 speed motor.	641
11-38	Wiring and Line Connection Diagram to Figure 11-37.	643

INDEX OF TABLES

a, the Value of, for Various Values of the Fraction of spp and Winding Pitch, Table for the Determination of, 564

Clearances, Mechanical, 47
Connection Diagrams for a Speed Ratio of 2:1, Table Showing the Numbers of, 588
Connection Diagrams for Top-to-Bottom or Long-Jumper Group Connection, Standard 3-Phase, 72
Connection Diagrams and Tables for Top-to-Top or Short-Jumper Group Connection, Standard 2-Phase, 72
Connection Diagrams and Tables for Top-to-Top or Short-Jumper Group Connection, Standard 3-Phase, 73
Connection Schemes for Multi-Speed Squirrel-Cage Induction Motors, Table of, 587
Connections, Series Star, Series Delta, 2-Parallel Star and 2-Parallel Delta, 395
Connection Table, Lap Winding, 2-Phase, 2-Pole, 90
  2-Phase, 4-Pole T-T, 94
  2-Phase, 6-Pole T-T, 98
  2-Phase, 8-Pole T-T, 103
  3-Phase, 2-Pole T-T, 113
  3-Phase, 4-Pole T-T, 119
  3-Phase, 6-Pole T-T, 130
  3-Phase, 8-Pole T-T, 145
  3-Phase, 10-Pole T-T, 157
  3-Phase, 12-Pole T-T, 178
  3-Phase, 14-Pole T-T, 191
  3-Phase, 16-Pole T-T, 192
  3-Phase, 18-Pole T-T, 193
  3-Phase, 20-Pole T-T, 195
  3-Phase, 22-Pole T-T, 197
  3-Phase, 24-Pole T-T, 199
  3-Phase, 26-Pole T-T, 201
  3-Phase, 28-Pole T-T, 203
  3-Phase, 30-Pole T-T, 205
Connection Table, Wave Winding, Fractional-Slot, Balanced, 8 poles, 54 slots, 455
  8 poles, 57 slots, 485
  8 poles, 63 slots, 493
  8 poles, 90 slots, 464
  8 poles, 105 slots, 490
  8 poles, 126 slots, 460
  8 poles, 135 slots, 498
  8 poles, 150 slots, 463
  10 poles, 72 slots, 471
  10 poles, 84 slots, 434
  10 poles, 96 slots, 439
  10 poles, 144 slots, 436
  10 poles, 168 slots, 475
  10 poles, 192 slots, 474
  12 poles, 81 slots, 456
  12 poles, 135 slots, 466
  14 poles, 90 slots, 443
  14 poles, 96 slots, 481
  14 poles, 120 slots, 446
Connection Table, Wave Winding, Fractional-Slot, Balanced, 14 poles, 180 slots, 484
  14 poles, 240 slots, 445
  16 poles, 108 slots, 458
  16 poles, 114 slots, 486
  16 poles, 126 slots, 494
  16 poles, 180 slots, 468
  16 poles, 210 slots, 491
  20 poles, 144 slots, 472
  20 poles, 168 slots, 435
  20 poles, 192 slots, 440
  20 poles, 336 slots, 477
  22 poles, 120 slots, 448
  22 poles, 144 slots, 449
  22 poles, 240 slots, 450
  24 poles, 171 slots, 488
  24 poles, 189 slots, 496
  26 poles, 132 slots, 499
  26 poles, 144 slots, 451
  26 poles, 168 slots, 452
  26 poles, 336 slots, 453
  28 poles, 180 slots, 444
  28 poles, 192 slots, 482
  28 poles, 240 slots, 447
Connection Table, Wave Winding, Fractional-Slot, Unbalanced, 6 poles, 42 slots, 531
  6 poles, 48 slots, 539
  6 poles, 96 slots, 537
  6 poles, 105 slots, 550
  12 poles, 66 slots, 542
  12 poles, 78 slots, 544
  12 poles, 84 slots, 533
  12 poles, 96 slots, 540
  12 poles, 102 slots, 548
  12 poles, 120 slots, 535
  12 poles, 192 slots, 538
  12 poles, 210 slots, 553
  18 poles, 96 slots, 554
  18 poles, 99 slots, 543
  18 poles, 114 slots, 557
  18 poles, 117 slots, 547
  18 poles, 126 slots, 534
  18 poles, 132 slots, 558
  18 poles, 138 slots, 560
  18 poles, 144 slots, 541
  18 poles, 150 slots, 562
  18 poles, 153 slots, 549
  24 poles, 240 slots, 536
Connection Tables for Unbalanced Fractional-Slot Wave Windings, List of, 564
Connection Table, Wave Winding, Progressive-Retrogressive, spp = 1½, 4 to 24 poles, 378
  spp = 2, 4 to 24 poles, 379
  spp = 2½, 4 to 24 poles, 380
  spp = 3, 4 to 24 poles, 381
  spp = 3½, 4 to 18 poles, 382
  spp = 4, 4 to 14 poles, 383
  spp = 4½, 4 to 12 poles, 384
  spp = 5, 4 to 10 poles, 384
  spp = 5½, 4 to 10 poles, 385
  spp = 6, 4 to 8 poles, 385
  spp = 7, 4 to 8 poles, 386
  spp = 8, 4 to 8 poles, 386

Connection Table, Wave Winding, Retrogressive, spp = 1½, 4 to 24 poles, 369
  spp = 2, 4 to 24 poles, 370
  spp = 2½, 4 to 24 poles, 371
  spp = 3, 4 to 24 poles, 372
  spp = 3½, 4 to 18 poles, 373
  spp = 4, 4 to 14 poles, 374
  spp = 4½, 4 to 12 poles, 375
  spp = 5, 4 to 10 poles, 375
  spp = 5½, 4 to 10 poles, 376
  spp = 6, 4 to 8 poles, 376
  spp = 7, 4 to 8 poles, 377
  spp = 8, 4 to 8 poles, 377
Connection Tables and Working Diagrams for Balanced Fractional-Slot Wave Windings, 500

Distribution Factors k_{dn} for Integral-Slot 3-phase Windings, Values of, 728
Distribution Table of the Lower Conductors for spp = 1½ (Wave Winding), 387
  of the Upper Conductors for spp = 1½ (Wave Winding), 387
  of the Upper and Lower Conductors for spp = 2 (Wave Winding), 388
  of the Lower Conductors for spp = 2½ (Wave Winding), 388
  of the Upper Conductors for spp = 2½ (Wave Winding), 389
  of the Upper and Lower Conductors for spp = 3 (Wave Winding), 389
  of the Lower Conductors for spp = 3½ (Wave Winding), 390
  of the Upper Conductors for spp = 3½ (Wave Winding), 390
  of the Upper and Lower Conductors for spp = 4 (Wave Winding), 391
  of the Lower Conductors for spp = 4½ (Wave Winding), 391
  of the Upper Conductors for spp = 4½ (Wave Winding), 392
  of the Upper and Lower Conductors for spp = 5 (Wave Winding), 392
  of the Lower Conductors for spp = 5½ (Wave Winding), 393
  of the Upper Conductors for spp = 5½ (Wave Winding), 393
  of the Upper and Lower Conductors for spp = 6 (Wave Winding), 394
  of the Upper and Lower Conductors for spp = 7 (Wave Winding), 394
  of the Upper and Lower Conductors for spp = 8 (Wave Winding), 394

Grouping of Coils for 2-Phase Windings, 221
  for 3-Phase Windings, 222
Grouping of Coils of Unbalanced 2-Phase Windings with a Number of Slots Divisible by the Number of Phases, 250
Grouping of Coils of Unbalanced 3-Phase Windings with a Number of Coil Slots Divisible by the Number of Phases, 251
Grouping of Coils and Unbalance in Magnitude and Phase Angle for 2-Phase Windings with a Number of Slots Not Divisible by the Number of Phases, 254
Grouping of Coils and Unbalance in Magnitude and Phase Angle for 3-Phase Windings with a Number of Slots Not Divisible by the Number of Phases, 256

Insulating Materials and Temperature Limits, Standard Classification of, 41
Insulating Materials, Guide for Stator Rewinding, 48
Insulation of Conductor, Materials for, 42
  Ground, Materials for, 43
  of End Winding, 46
  of End Winding, Materials for, 45
  of Normal Coil for Class A Rotor Wave Windings, 47
Insulation for Class A, B, and H Coils, Normal Ground, 44
Interlaced Windings per Phase (the Number of) and the Winding Pitch, Table for the Determination of the, 501

Pitch Factors (k_{pn}) for Harmonics at Different Pitches for Integral-Slot Windings, Values of, 731
Pitch, Winding, and the Number of Interlaced Windings per Phase, Table for the Determination of the, 501
Pitch, Winding, and the Value of a for Various Values of the Fraction of spp, Table for the Determination of the, 564

rpm, Synchronous, for Different Numbers of Poles and Different Frequencies, 3

spp for 2-Phase Windings, Master Table of, 74
spp for 3-Phase Windings, Master Table of, 76
spp for 2-Phase Windings with a Number of Slots Not Divisible by the Number of Phases, 252
spp for 3-Phase Windings with a Number of Slots Not Divisible by the Number of Phases, 253

Temperature Limits and Insulating Materials, Standard Classification of, 41

Unbalance in Magnitude and Phase Angle for 2-Phase Windings with a Number of Slots Not Divisible by the Number of Phases, and Coil Grouping, 254

INDEX TO TABLES (Cont'd.)

Unbalance in Magnitude and Phase Angle for 3-Phase Windings with a Number of Slots Not Divisible by the Number of Phases, and Coil Grouping, 256
Unbalance of 3-Phase Windings with a Number of Slots Divisible by 3, 263

Voltage of Various 3-Phase Connections, Percentage, 593

Voltage of Various Connections from 3-phase to 2-phase and Vice-Versa, Percentage, 605

Wedge Dimensions for Wound Rotors, 50
Working Diagrams and Connection Tables for Balanced Fractional-Slot Wave Windings, 500
Working Diagrams and Connection Tables for Unbalanced Fractional-Slot Wave Windings, List of, 564

MISCELLANEOUS TABLES

Copper Wire, Data on Bare and Insulated Round, 735
  Data on Square Bare, 737
Currents of Single-phase Motors, Approximate Full-load, 740
Frequency and Voltage Variation on Induction Motor Characteristics, General Effect of, 733
Insulation Covering for Square or Rectangular Wire,Nominal Thickness of, 738
Operating Data (Approximate) for Constant Speed Squirrel Cage Induction Motors from 1/2 Horsepower to 200 Horsepower, 741
Operating Data (Approximate) for Constant Speed Squirrel Cage Induction Motors and for Wound Rotor Induction Motors from 250 to 1000 Horsepower, 743
Sine Values for 45 to 90 Degrees for Use in Figuring Pitch Factors, 739
Voltage and Frequency Variation on Induction Motor Characteristics, General Effect of, 733

GENERAL INDEX

A

a, value and sign of, 402
Abnormal front-pitches, 266, 396, 502
Angle, between 2 slots, 673
  magnetic field, 673
Arrangement of conductors in wave windings, 32
Arrangement of leads, 22

B

Back pitch, 264, 402, 506
Balance, conditions of, 212, 682
Balanced fractional-slot lap windings, 207, 212, 670, 683
Balanced fractional-slot wave windings, 264, 396
Banding end windings, 36
Beginnings of phases, 4, 53, 60, 66, 216, 218, 237, 292, 407, 409, 417, 430, 514, 509, 519, 681
Bottom coil side, 22
Bottom-to-bottom connection, 16, 53
Bottom-to-top connection, 15, 53, 565
Brick winding, 20

C

Changing the number of poles, 565
  a capacitor-start motor to a split-phase motor, 649
  a 2-value capacitor motor with transformer to a capacitor start-motor, 650
  from series to 2-parallel or other combination by use of connection tables, 55
  the number of parallel circuits, 592
  the spacing between the beginnings of the phases, wave windings, 278
  a split-phase motor to capacitor-start motor, 649
Checking a 2-phase winding, 60
  a 2-phase or 3-phase winding by a dummy rotor or steel ball, 61
  a 3-phase winding, 66
  a wave winding, 662
  the spp of a wave winding, 294
Chord factor, 597
Chorded winding, 4
Classification of a-c windings, 5
  of single-phase motors, 609
Clip insulation, 35
Clips, number of, at connection end, wave windings, 270, 300
  at end opposite leads, wave windings, 279
Clockwise connection of conductors, wave windings, 404
Coil, 1
Coil group, 1
Coil grouping, 208
Coil grouping tables, how to use them, 208, 233
Coil pitch, 4
Coils, left-hand, 15, 22, 266
  pulled straight-up wound, 17
  right-hand, 15, 22, 266
  throw, 15, 16
Comparison between balanced and unbalanced lap windings, 706
Comparison between balanced fractional-slot winding a = + 1 and a = - 1, 410
Comparison between balanced fractional-slot winding a = + 2 and a = - 2, 418, 426
Comparison of retrogressive connection with progressive-retrogressive connection, 273, 277
Conditions of balance, 212, 682
Conductor, 1
Conductors, arrangement of, in wave winding, 32
Conductor distribution tables, laying out, 291
  how to use them, 277
Conductor insulation, 25, 42, 622
Connection diagrams, how to use them, 52, 207, 237, 626
Connection, long jumper for 2-parallel circuits, 59
Connection, long pitch, advantage of, 272
  short pitch, advantage of, 272
Connection table, laying out, for wave windings, 291
Connection tables, use of them, 52, 277, 285, 397, 502
Connectors required for series connection of all parts of the phase, of a balanced fractional-slot wave winding, 407
Consecutive waves, 405
Consequent pole, 637
Consequent pole winding, 565
Copper losses, 20
Core, rewinding an old, 606
Counterclockwise connection of conductors, wave windings, 404
Creepage distances, 31
Cycle, 1
Cyclic shift of coils, 683
Cyclic shift, more than one coil, 687

D

D-series, 403, 507, 691
Delta, reconnecting from, to star, 591
Delta connection, 69, 248, 306
Designation of pole-phase groups, 51, 63
Direction of rotation for single-phase motors, 632
Direction of rotation, predetermining for split-phase motors, 644

Distribution chart, single-phase winding, 619, 624
Distribution factor, 597, 674, 683, 719
  of single-phase windings, 723
Doubly chorded windings, 689, 696
Dual voltage connection, 61, 69
Dual voltage motors, 634

E

Electrical faults, common, a-c windings, 658
End windings, banding, 36
End windings, insulation, 24, 27, 32, 33, 45
Equal distribution parts, number of, 208
Equal windings parts, number of, 211, 212
Equalizer connections, 70, 71, 626

F

Flux, 589
Fractional-pitch winding, 4
Fractional-slot lap windings, 207, 238
Fractional-slot wave windings 264, 396, 502
Fractional-slot windings, 9, 10
Frequency, 1
  reconnecting for another, 594
  rewinding for different, 649
Front pitch, 265, 272, 402, 506
Full pitch winding, 4

G

Ground insulation, 26, 27, 33, 43
Ground insulation for Class "A" wave windings, 47
Grounds, 658
Guide for stator rewinding material, 48

H

Horsepower, constant for 2-speed windings, 567
  determination of 606

I

Insulation, clips, 35
  conductor, 25, 42, 622
  end windings, 27, 32, 33, 45
  ground, 25, 33, 43
  ground for class "A" wave windings, 47
  jumpers, 29
  lead, 28
  materials, Class O, A, B, and H defined, 41
Insulation, slot, 32, 622
  strand, 25
  stub connections, 29
  support, 35
Integral-slot lap windings, 9, 10, 51
Integral-slot wave windings, 301

J

Jumper, insulation, 29
  long, 54, 58, 65
  long coonnection for 2-parallel circuit winding, 59
  reversing, 266
  short, 58, 65

L

L-Connection, 642, 647
Lap winding, balanced fractional-slot, 207, 675, 683
Lap windings, unbalanced fractional-slot, 238, 241, 701, 704
Laying out, conductor distribution tables, 291
  connection tables, wave windings, 291
  a working diagram for balanced fractional-slot winding, 399
  a doubly-chorded wave winding, 696
Layout of 2-phase windings, 56, 214
  of 3-phase windings, 62, 217
  of singly chorded balanced fractional-slot windings, 692
  of a wave winding with number of slots not divisible by 3, 525
  of a winding with a = ± 1, 408
  of a winding with a = ± 2, N = even number, 415
  of a winding with a = ± 2, N = odd number, 425
  of winding with a larger than 2, 430
  of a winding with the number of slots divisible by 3 and denominator of spp = 3, 508
  of a winding with the number of slots divisible by 3 and denominator of spp = 6, 512
  of a winding with the number of slots divisible by 3 and the denominator of spp = 9, 517
Lead, insulation, 28
Leads, arrangement of, 22
  finishing, 21
  starting, 21
  equal mechanical spacing, of, 413
Left-hand coils, 266
Line connection diagram, 632
Long jumper, 58, 65
Long jumper,connection, 53
  use of, 54
Long-pitch, 266

Long-pitch, short-pitch connection, 268
Long throw connection, 629
Longer front pitches, number of, 271, 509, 514
Losses, copper, 20
Lower conductor, 264

M

Magnetic unbalance, 70
Materials,for conductor insulation, 42
  for ground insulation, 43, 44
  for end winding insulation,45, 46
Mechanical clearance, 30, 35, 47
Mechanical spacing of leads, 413

N

Neutral point of a 3-phase winding, 69
Noise, 601
Normal front pitches, 272
Number of clips at connection end of a winding, 279, 300
Number of conductors per slot larger than 2, 695
Number of poles, 1, 11
Number of pole-phase groups, 3
Number of slots in a repeatable winding part, 403
Numbering of pole-phase groups, 51

O

Open circuits, 664
Output constant, 606

P

Parallel circuits, changing the number of, 592
  number of, when less than number of repeatable winding parts,214
  maximum number of, when using long jumpers, 210
  maximum number of, when using short jumper, 210
  lap windings, maximum number of, 52, 65, 209, 210, 213, 235,237, 239, 244, 670, 682, 690
  wave windings, maximum number of, 307, 317, 405, 417, 512, 517, 526, 695, 697
Parallel connection, types of, for 3-phase windings, 64
Parallel paths, 2 or more, for the balanced fractional-slot wave winding, 433
Parasitic currents, 19
Pitch factors, single phase windings, 723
  3-phase windings, 719
Polarity of a coil side, 406
  of the ends of winding parts,406, 412, 415, 420, 425, 428, 432, 524
  of the starts of winding parts, 405, 412, 415, 420, 425, 428, 432, 524
Pole-phase groups, 3
  designation of, 51, 63
  numbering of, 51
  sequence of, 215, 217, 219, 233, 235, 247, 676, 680
  split, 235
  total number of, 3
Pole pitch, 3
Poles, changing the number of, 565
  number of, 1, 11
Power output, 590
Progressive connection, 267, 272
Progressive-retrogressive connection, 266, 270, 275
  comparison with progressive, 273, 277
Pulled coils, cross-over, 17

R

Reconnecting a capacitor start motor for different voltage, 646
  a permanent split and a 2-value capacitor motor for different voltage, 647
  a winding from delta to star, 591
  a winding from star to delta, 591
  an old winding, factors to consider when, 589
  for another frequency, 594
  for another number of phases, 602
  for another speed, 598
  for another voltage, 590
  a split-phase motor for different voltage, 645
Reference points for working diagrams, 298, 299, 398
Repeatable distribution parts, number of, 211, 212
Repeatable winding parts, number of, 211, 402, 670, 692
Repeatable winding parts, number of slots,in, 403
Retrogressive connection, comparison with progressive-retrogressive, 273, 277
Retrogressive (SP) connection,using left-hand coils, 268
  using right hand coils, 272
Reversible motors, 630
Reversing jumper, 266
Reversing split-phase motors, 644
Rewinding a capacitor-start motor for different voltage, 646
  a permanent-split and a 2-value capacitor motor for different voltage, 647
  a split-phase motor for different voltage, 645
  an old core, 606

Rewinding for different break-down torque at same voltage, 648
  for different frequency, split-phase motor only, 649
Rewinding materials, guide for stator, 48
Right-hand coils, 266
Rotation,direction for single-phase motors, 632
  predetermining direction for split-phase motor, 644
  reversing, single phase motors, 644

S

Scott, or T-connection, 603
Second chording, 688
Semi-closed slot, 5
Sequence of pole-phase groups, 215, 217, 219, 233, 235, 247, 676, 680
Series of coils, 264
Shifting repeatable parts, 688
Short circuits, 659
Short jumper, 58, 65
Short-jumper connection, 53
Short pitch, 266
Short-pitch connection, 268
Short-throw connection, 629
Shorter front pitches, number of, 270, 275
Single phase, auxiliary windings, 639
  intermediate windings, 639
  main windings, 639
  2-speed windings, 619
Slot chart, 246
Slot insulation, 32
Slot pitches, 265
Slot shapes for squirrel cage windings, 37, 39
Slot shapes for stators and rotors, 6
Slot star, 670
Slots per pole per phase, 2
Speed, reconnecting for another,598
Split pole-phase groups, 235
Spp, 2
  checking for wave winding, 294
Star connection, 69, 306
Star connection of the phases, 306
Star reconnection from, to delta, 591
Strand, definition, 1
  insulation, 25
Stranding of rectangular conductors, 19, 34
Stub-connection insulation, 29
Support insulation, 35
Swing connection, 632, 646, 647
Synchronous speed, 2

T

T-connection, 642, 648
T- or Scott connection, 603
Terminal markings, single-phase windings, 626
  3-phase lap windings, 57, 64
Tie rings, insulation, 29
Top coil side, 22
Top-to-bottom connection, 15, 53, 565
Top-to-top connection, 16, 53
Torque, 590
  constant, for 2-speed windings, 567
  locking, 601
  variable, for 2-speed windings, 567
Trouble chart for induction motors, 667
Turn, definition,of, 1
Turns, per phase, 18, 589, 597
Two-speed motors, 565, 637, 639
Two-speed windings for constant horsepower, 567
  constant torque, 567
  variable torque, 567
Types, single phase motors, definition of, 609

U

Unbalance, kinds of, 232, 701
  Magnetic, 70
  Magnitude of, 529, 711
  Permissible degree of, 248
Unbalanced fractional-slot lap windings, 232, 238, 241, 701, 704
Unbalanced fractional-slot wave windings, 502, 707, 709
Upper conductors, 264

V

Vibration, 629
Voltage, reconnection for another, 590
Volts per turn, 17

W

Wedges dimensions for wound rotors, 36, 50
  shapes, 36
Winding, brick, 20
  chain, 5, 6
  chorded, 4
  distributed, 5, 6
  doubly chorded, 689
  flat diamond, 8, 12, 13
  fractional pitch, 4
  full pitch, 4
  hand, 613
  round end, 7, 12, 13
  single layer, 5
  skein, 7, 615
  spread diamond, 8, 12, 14, 15
  mould, 6, 12, 614
  2-layer, 3, 5, 9

Winding, 2 speeds with one, 565
  2-zone, 719
  3-zone, 565, 596, 719
  6 zone, 565, 596, 719
Winding parts, starts and ends, 292, 405, 409, 417, 430, 509, 514, 519, 521
Winding pitch, 265, 402, 506, 691
  even, 402
  odd, 402
  of balanced fractional-slot wave windings, 401, 406
  of unbalanced fractional-slot wave windings, 506
  series, 403, 507
Windings, balanced fractional-slot, lap, 9, 10, 11, 207, 212, 670, 683
  balanced fractional-slot, wave, 264, 396 691
  integral-slot, 9, 10, 264, 307
  interlaced, 405, 567, 570
  squirrel, cage, kinds of, 37
  2-layer, 5
  2-phase, 1
  3-phase, 1
  unbalanced fractional-slot, lap, 232, 238, 241, 701, 704
  unbalanced fractional-slot, wave, 502, 707, 709
Windings, wave, 9, 10, 11
  wave, with more than 2 conductors per slot, 301, 317
  2 speeds with two, 567
  3 speeds with two, 570
  4 speeds with two, 570
Wiring diagram, 632
Working diagram, general, balanced fractional-slot wave windings, 400
  general, progressive-retrogressive windings, 299
  general, retrogressive windings, 298
  general, unbalanced fractional-slot wave windings, 505
  reference points for, 289, 299, 398, 400, 505
  use of, 285
Working diagrams, 285, 398, 505
  development of, 279
Wrong connections, 661
Wrong number of poles, 664
Wrong voltage, 663
Wye connection, 69, 306

Y

y - series, 511, 691

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